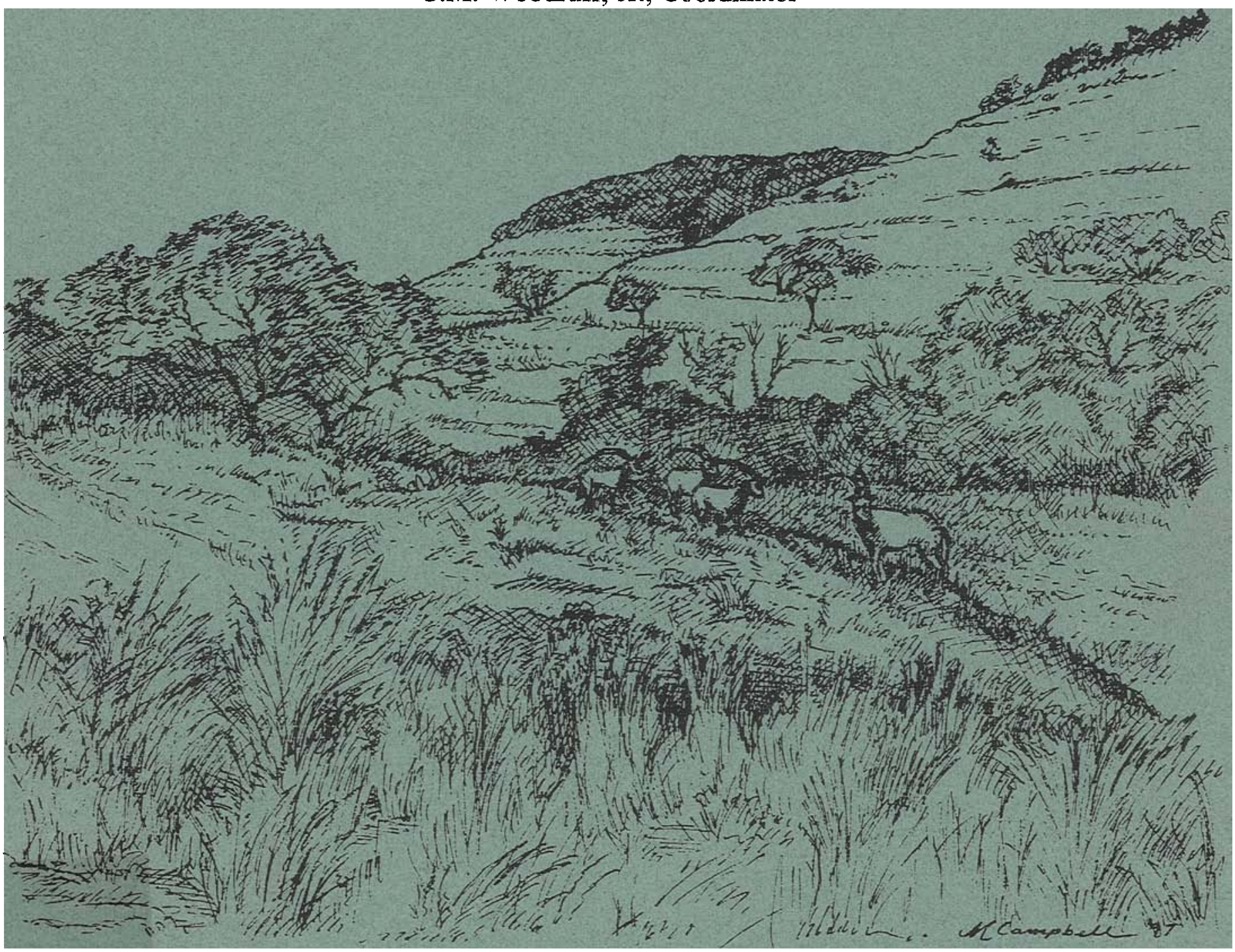
ENVIRONMENT and LAND RESTORATION in the CENTRAL TEXAS HILL COUNTRY

A Geologic Excursion to Selah, Bamberger Ranch, Blanco County, Texas

C.M. Woodruff, Jr., Coordinator



GUIDEBOOK 17

Austin Geological Society

1997

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Contributions by:

John B. Ashworth, J. David Bamberger, Robert W. Baumgardner, Jr.,
Margaret C. Campbell, David W. Dunlap, Glen L. Evans, H.S. Nance,
David H. Riskind, Peter R. Rose, Charles W. Sexton, and L.P. Wilding

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Austin Geological Society
P.O. Box 1302
Austin, Texas

5 April 1997

He likes a bulldozer, crushing agent of change. Likes lowering its bright-worn battering blade and aiming it at the thick gnarled junipers and knocking them down and leaving behind him a strewn path full of edge-standing limestone boulders clutched by the roots that, uptorn, still hold on . . . Likes clearing, cleaning, burning off the dried debris. Likes watching the doveweed and the sunflowers and the Johnson grass break through the bared ground the first year, and then the grain-rich native pasture stuff that, nursed, lays itself down on the hills' slopes in a rug that soaks up rain and opens cool seep-springs all along the draws.

John Graves
Goodbye to a River
Alfred Knopf, 1960, p. 269

We only hold our land in trust for a few years while we live, and since countless others will use it after we are gone, each of us has an obligation to maintain our land and related resources in good condition for our own use and for those who will follow.

Charles Petit
Flat Top Ranch
University of Oklahoma Press, 1957, p. xviii

Front cover: Scimitar-horned oryx on the hills at Selah. Pen-and-ink drawing by Margaret C. Campbell.

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FOREWORD

When I first purchased the land for Selah I actually wanted a place that had been abused, neglected, and overgrown in order to emulate the work of one of my favorite authors, Louis Bromfield. He created a beautiful example of restored farmland in Ohio from a "farmed out" area called Pleasant Valley which exists today as Malabar Farm State Park. It is open to visitors, houses an important library, and is available for research on holistic farming practices. The land I found in Blanco County 27 years ago presented conservation and environmental challenges quite different from those of the rolling hills of Ohio. However, I felt sure that with habitat restoration and consistently good conservation practices the results in the Hill Country of Texas would be the same as Bromfield experienced in Ohio.

The Bamberger Ranch, which is 5,500 acres, had serious second growth cedar problems on much of it, and some was what we call "wall to wall cedar". The removal of much of that cedar was the first big challenge, and the establishment of native grasses the second.

The miracles of springs, abundant water, and diverse wildlife followed those accomplishments. Many acres of cedars remain, especially the big old ones, in areas where the Juniper historically lives, such as along creeks and in canyons. We recognize and respect its place in the ecology of the area, and its importance for wildlife cover and movement, as well as the source for nesting material for the endangered Golden-cheeked Warbler.

It was only after the restoration was well underway, and friends in the environmental, wildlife, and professional arena started visiting the ranch, that I began to understand what a wonderful piece of the Texas Hill Country I had, and then saw that the ranch could serve an important role as an outdoor laboratory and model to create awareness about conservation and the environment. We dedicated the ranch to environmental education, conservation and research and began inviting organized groups of students, conservation organizations, professional groups, and landowners to visit and share our experience.

One does not begin nor complete a project of this magnitude alone. Leroy Petri, a self taught and practical engineer joined me in 1970. He currently is responsible for all the physical facilities and equipment. The lakes, roads, fences and some of the buildings were built by him. In 1974 "Buddy" Francis joined us as Livestock manager. He was previously a technician with the U. S. Soil Conservation Service. His special ability is in grass management and his work here earned the Ranch the "Excellence in Grazing Management" award from the Society for Range Management. Randy Lenz started on the ranch as a high school student in 1974, working 2 summers here. Randy started on the ranch as a high school student in 1974 and worked 2 summers here, which influenced him to enroll at Texas A & M and earn a degree in wildlife management. He returned to the ranch as full time Wildlife Manager in 1984. Jim Rhoades, an arborist with the City of Austin, has worked weekends and holidays since 1985 on our tree growing and tree management program. Margaret Campbell, an educator and naturalist joined the staff in 1995 to develop and deliver educational programs for our students and visitors. Selah, a place to pause and reflect, could not deliver its message without these talented dedicated people. I'm thankful to have them as friends.

A new experience for the ranch, one that will contribute immensely to our body of knowledge and to our educational programs, is the visit and report of the Austin Geological Society. We welcome your interest and presence.

J. David Bamberger
Land Steward
Blanco County, Texas
March, 1997

ACKNOWLEDGMENTS

We are grateful to J. David Bamberger for making his ranch available to the Austin Geological Society and for taking time to participate in the field trip. His ongoing efforts in the management of the land, water, and habitats of this ranch constitute a remarkable experiment that spans decades. His experiences are invaluable; we salute him for his work and thank him for recounting key points to the participants of this excursion. We thank Margaret C. Campbell for facilitating various logistical aspects of the trip and the guidebook as well as for her artistic contributions. Margaret's beautiful pen and ink drawings grace the cover of this book as well as various other places in the volume. Margaret coauthors the checklist of birds, and she illustrates the article on native grasses.

We extend thanks to the other contributors to the field trip. Each of these people brought expertise and vision to bear on the environment of this ranch in particular or on the Hill Country/Edwards Plateau in general. With the variety of viewpoints presented herein, we bridge scientific disciplines as disparate as geology and agrostology, and pedology and ornithology. Moreover, we view this part of Central Texas through historical perspectives: One narrative addresses this part of the Western frontier during the Nineteenth Century. Another includes personal reflections on climate and geologic processes focusing especially on droughts during the Twentieth Century. In addition to our having addressed both natural history and human history (including history that is read and history that is recollected), we are presented a view of this particular ranch through the lens of the photographer, which provides another artistic perspective complementary to Margaret's drawings. In short, we have a confluence of arts as well as sciences. It is necessary; such an area and such an experiment cannot be addressed in a truly meaningful way using only a single set of tools employed by a single discipline. Broken down into its component parts, we gain only a fragment of reality. Complexity demands a holistic view.

Special thanks are extended to Dr. Jeff Pittman, of the University of Colorado at Denver, for allowing us to reproduce his map of the dinosaur trackway. General administrative support was provided by Mary Ambrose, President of Austin Geological Society and Elizabeth E. Huebner. For production of the guidebook, we are indebted to Susann V. Doenges, Editor-in-Chief at the Bureau of Economic Geology, and to Susan J. Lloyd, who provided key services in converting the various guidebook papers and illustrations into a common format for printing.

Robert H. Blodgett
Charles Woodruff, Jr.
Field Trip Committee
Austin Geological Society

Selah—A Pause in Time and Space

> Therefore will not we fear, though the earth be removed, and though the mountains be carried into the midst of the sea;
> Though the waters thereof roar and be troubled, though the mountains shake with the swelling thereof. Selah.
>
> Psalm 46: 2-3
> King James Version

C.M. Woodruff, Jr.

Bamberger Ranch comprises approximately 5,500 acres in Blanco County, Central Texas. The ranch, owned and managed by J. David Bamberger, has undergone a remarkable transformation over the past two and a half decades. Before 1970, the tract was overgrazed and eroded, having extensive cedar brakes and scant diversity of wildlife. A view across a fenceline boundary of the ranch reveals the changes brought about during the recent past. There, cedar brakes and gullied hillsides across the fence contrast with the park-like savanna of Bamberger Ranch, which now harbors abundant and varied wildlife (notably endangered migratory warblers and vireos), and rejuvenated springs that reflect an ongoing reallocation of the local water budget. By dint of purposeful grazing management, judicious clearing of overstory, and reestablishment of native grasses, more moisture is retained and meted out slowly on a landscape that, over the past century, had been given over to hydrologic extremes: drought during dry periods and flashy runoff with attendant erosion during wet weather.

The name of the ranch is Selah, from the Hebrew word *selâ*, meaning "pause," or "rest." It is a curious name for a parcel of land whose restoration has been measured in numbers of lopping shears, brushhooks, and chainsaws consumed in clearing the land. Yet the name is appropriate in the context of the word "selah" in our English-speaking world, embedded in selected Psalms of the Bible. It is not part of the text, not part of the poetry of the psalms but instead is a device that helps to set the poetic meter. It is not to be read, but is a silent instruction commanding the cantor or reader to pause and take a breath while the message sinks in with the congregation.

Thus, Selah, as the name of the ranch, invites pause and reflection. An appropriate focus of this reflection might be the changes in this parcel of land wrought by a vision avidly pursued and executed. And the changes here invite contemplation in a broader context to include general human uses of, and responsibilities for, the natural landscape. Indeed, the work done at Selah and the results accomplished over the years present a hopeful counterbalance to dire predictions of impending global change: abused land can be brought back to environmental health—one parcel at a time.

A lesson from Selah is that there is a tangible connection between land and vision and actions, just as Western religions teach that there is a metaphorical connection between words and intentions and deeds. Religious traditions, with their words of praise of Creation and of injunction to humanity, are thereby linked to our day-to-day work and our responsibilities as (presumably) intelligent beings. A lesson from Selah is that—just as thoughtless human action may decrease the diversity and viability of the land—human creativity may also ameliorate past abuse of the land compounded on natural processes. We can do little to alleviate the periodic floods and droughts that occur in Central Texas; they are part of the natural order of things. But we can be better stewards of the land. This is demonstrated at Selah.

The pause commanded by the word "selah" implies a boundary in time. And boundaries in time and space provide a unifying concept and theme underlying this 1997 AGS excursion. The Bamberger ranch is in proximity to several notable geographic and geologic boundaries. Selah is situated along the easternmost outlier of the contiguous Edwards Plateau (that is, the continuous, gently-sloping upland surface, underlain by Edwards Limestone). But the flat-topped uplands constitute only a small fraction of the ranch; most of the tract comprises steep slopes and incised drainageways typical of the Central Texas Hill Country. Hence, here we see a boundary between the dissected Hill Country and the flat-topped Edwards Plateau, which also marks the boundary between the plateau segments of the Edwards aquifer and various members of the Trinity aquifer that produce groundwater from Cretaceous strata underlying the Edwards. The ranch also includes a small segment of the divide separating surface drainage to the Pedernales River from that draining to the Blanco River to the south. This watershed is the boundary separating two of the major coastward-flowing river systems of Texas: the Colorado to the north and the Guadalupe to the south.

Boundaries occur in the third dimension as well. Although hidden from view, some of these discontinuities represent profound geologic breaks with far-reaching ramifications. Basal Cretaceous strata lie 400 to 500 ft below the land surface, and those strata constitute important groundwater-bearing horizons that supply Hill Country homesteads and towns. And the base of the Cretaceous is marked by a dramatic discontinuity in bedrock and in geologic time, for across this unconformity lie members of the Ellenburger Group, a flint-hard carbonate rock unit that straddles the Cambrian-Ordovician boundary—a half-billion years old. Thus, across that erosional boundary are missing rock units representing an interval of geologic time spanning approximately 400 million years.

This geologic hiatus spans all the Paleozoic Era after the Ordovician, as well as all the Mesozoic Era prior to the Cretaceous. Geologic Periods absent across this boundary include the Silurian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, and Jurassic. During this interval of time, the Late Paleozoic Ouachita Mountain belt was uplifted, subsequently eroded, and subsided beneath the encroaching Mesozoic sea of the newly opened Gulf of Mexico. This orogeny resulted from the collision (or close encounter) of the southern margin of North America with a converging continental mass of unknown origin from the south. The remnants of this deformed zone lie buried a mere 12 miles south of Selah, but no trace is known to remain beneath the ranch. Likewise, during this missing interval, organic evolution progressed with the rise of complex marine ecosystems, the colonization of life on land, and the appearance of the first amphibians, reptiles, and birds. And at the Permian-Triassic boundary there occurred a great, unexplained cataclysm of life on Earth, when approximately 80 percent of all species became extinct. Selah.

Other significant hiatuses in geologic time occur on or beneath the ranch. In 1986, a wildcat exploration well (Rainer #1 Whittington) was drilled to 2,970 ft on an adjacent property. This well penetrated the base of the Cretaceous at about 570 ft and cut through about 2,180 ft of Cambrian/Ordovician carbonate strata of the Ellenburger and Wilberns Groups, until, at a depth of 2,750 ft, Precambrian granite was encountered. This granite probably is part of a high-standing erosional monolith. The entire Riley Group of Cambrian strata is absent, having been eroded away or never deposited on this presumed high-standing feature. Assuming that the granite penetrated by the borehole is of the same age as similar rocks exposed nearby, this erosional hiatus encompasses about 600 million years—more time than that represented by the entire sequence of the Phanerozoic (that is, all the ensuing time since the Precambrian).

Another major hiatus in time occurs at the ground surface on the ranch. Exposed rocks are on the order of 100 million years old; and during the ensuing time, another cataclysmic boundary in Earth history occurred: At the end of the Cretaceous Period, about 65 million years ago, life on Earth was subjected to another great die off. The currently prevailing hypothesis postulates that an asteroid struck the northern part of the Yucatan Peninsula, generating enormous tidal waves, vaporizing huge volumes of rock, creating a vast crater, and igniting widespread fires owing to the world-wide fallout of white-hot ejecta. Such an event likely caused long-term climate changes with extremes ranging from a "nuclear winter" scenario owing to skies having been blackened by fire and dust, to global warming owing to increased greenhouse gases. It is hypothesized that this event resulted in the demise of dinosaurs as the dominant creatures on Earth and the abrupt end of many other species as well. Across that boundary in time, the Mesozoic Era ended and the Cenozoic Era began with the expansion of mammals to eventually become Earth's dominant life form. The Balcones Escarpment was etched into the landscape after the main Balcones Fault events during the Miocene Epoch (~15 million years ago). And the terrain features that we see today probably formed after those tectonic events.

The boundary theme extends beyond the ranch itself to include the remarkable natural divisions that are crossed en route from Austin. The Balcones Escarpment marks the eastern margin of the Edwards Plateau/Hill Country region and is itself a boundary separating two grand physical divisions of North America: the Great Plains to the west; the Coastal Plains to the east. This fault-controlled boundary is not a razor-sharp edge, but it is nonetheless an ecological borderland (an ecotone). Across the Balcones Fault Zone, dramatic changes occur in bedrock and topography, weather and climate, soils and flora and fauna, and a variety of ongoing processes, notable among which are surface stream regimes and groundwater storage and transfer.

Ecologically, the Balcones Escarpment marks the beginning of the American West; across that fault line begins the habitats of the jackrabbit, the roadrunner, and the scrub jay; it is the domain of the ashe juniper, the madrone tree, and eventually, the piñon pine. Water is the key resource in delimiting the ecological west (as opposed to the popular image of the "West" with its cowboy culture that can occur anywhere).

A different datum to delineate the boundary between east and west was employed by Walter Prescott Webb, in his classic book, *The Great Plains*. He drew the boundary along the 98th Meridian, noting the close correlation between this longitude line and the 30-inch rainfall isohyet. Webb denoted this line an "institutional fault" marking the beginning of the dry country of the American West with its multiple influences on social, economic, and political activities. Notably, Webb's standpoint for using this cartographic boundary was his Friday Mountain Ranch, which lay about 2.5 miles east of the 98th Meridian but which was also bisected by the Mount Bonnell Fault. This true geologic fault was probably a major influence on Webb's perception of his institutional fault.

Bamberger Ranch lies west of the 98th Meridian, although east of the 30-inch isohyet (fig. 1). In this part of Central Texas, the 30-inch isohyet is displaced westward as a broad zone of increased rainfall controlled by topography, probably by the Balcones Escarpment and the dissected Hill Country reaches of the Pedernales, Blanco, Guadalupe, and Medina River systems. Bamberger Ranch occupies the easternmost edge of the topographic upland—a true plateau table land—that extends for more than 300 miles to eventually merge with the Llano Estacado and the rest of the High Plains beyond. The Hill Country terrain that characterizes most of the ranch extends east to the Balcones Escarpment. Nestled in the well-watered valleys of the Hill Country are the westernmost extent of many eastern riparian species (including local disjunct refuges of isolated eastern species). Conversely, the drier Hill Country uplands harbor typical western species that have their easternmost boundary at the Balcones Escarpment. Thus, there is a surprising juxtaposition of environments and a rich biologic diversity. Baldcypress trees occupying spring-fed stream bottoms coexist with yucca and cholla and prickly pear on nearby upland slopes. In summary, this borderland is defined by a limiting resource, namely water; the distribution of water on the landscape is controlled by the vagaries of rainfall coupled with the geologic/geomorphic setting.

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Raisz, Erwin, 1957, Landforms of the United States: Sixth revised edition, approximate scale 1 inch = 70 miles.

View from High Lonesome

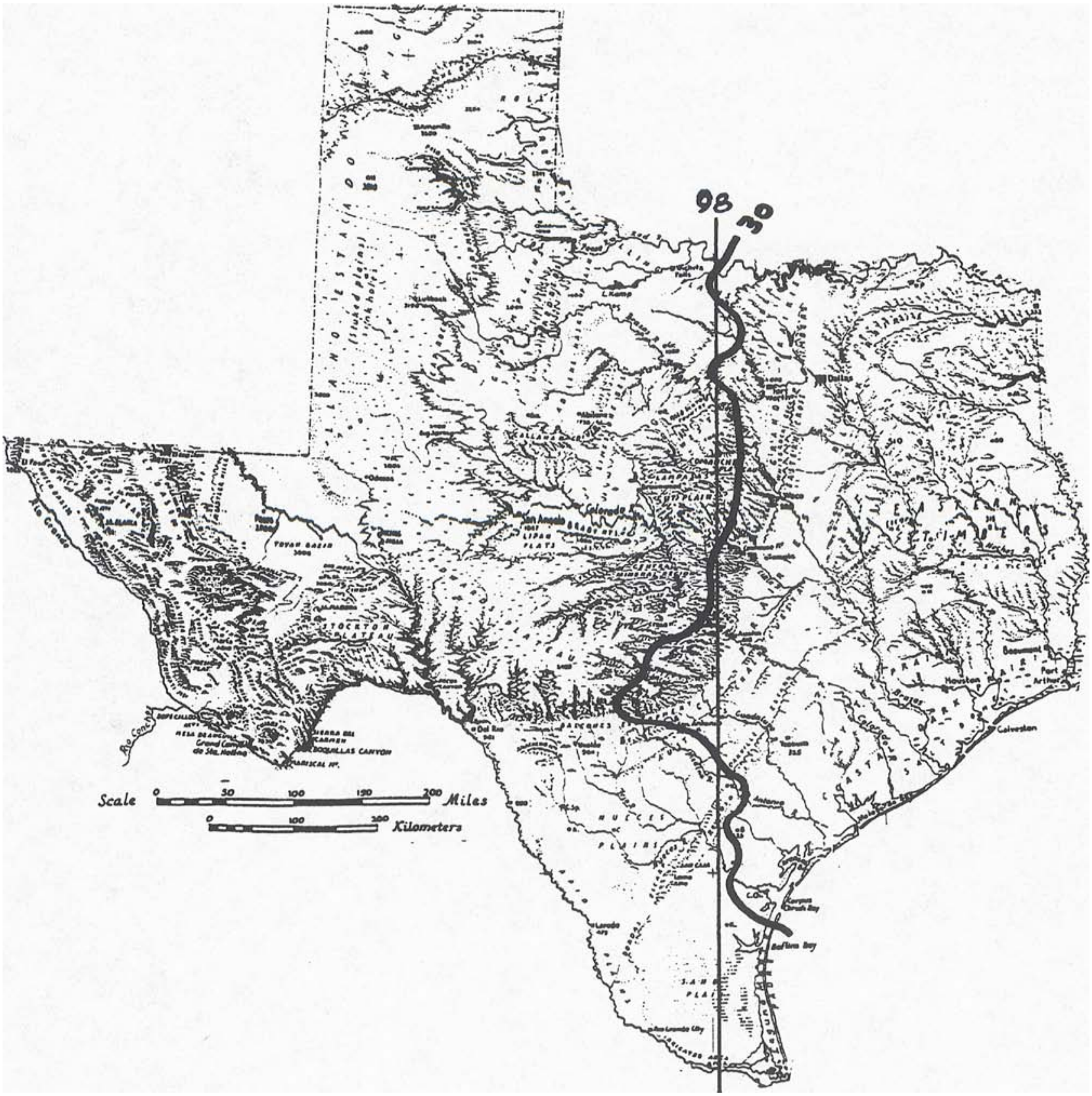


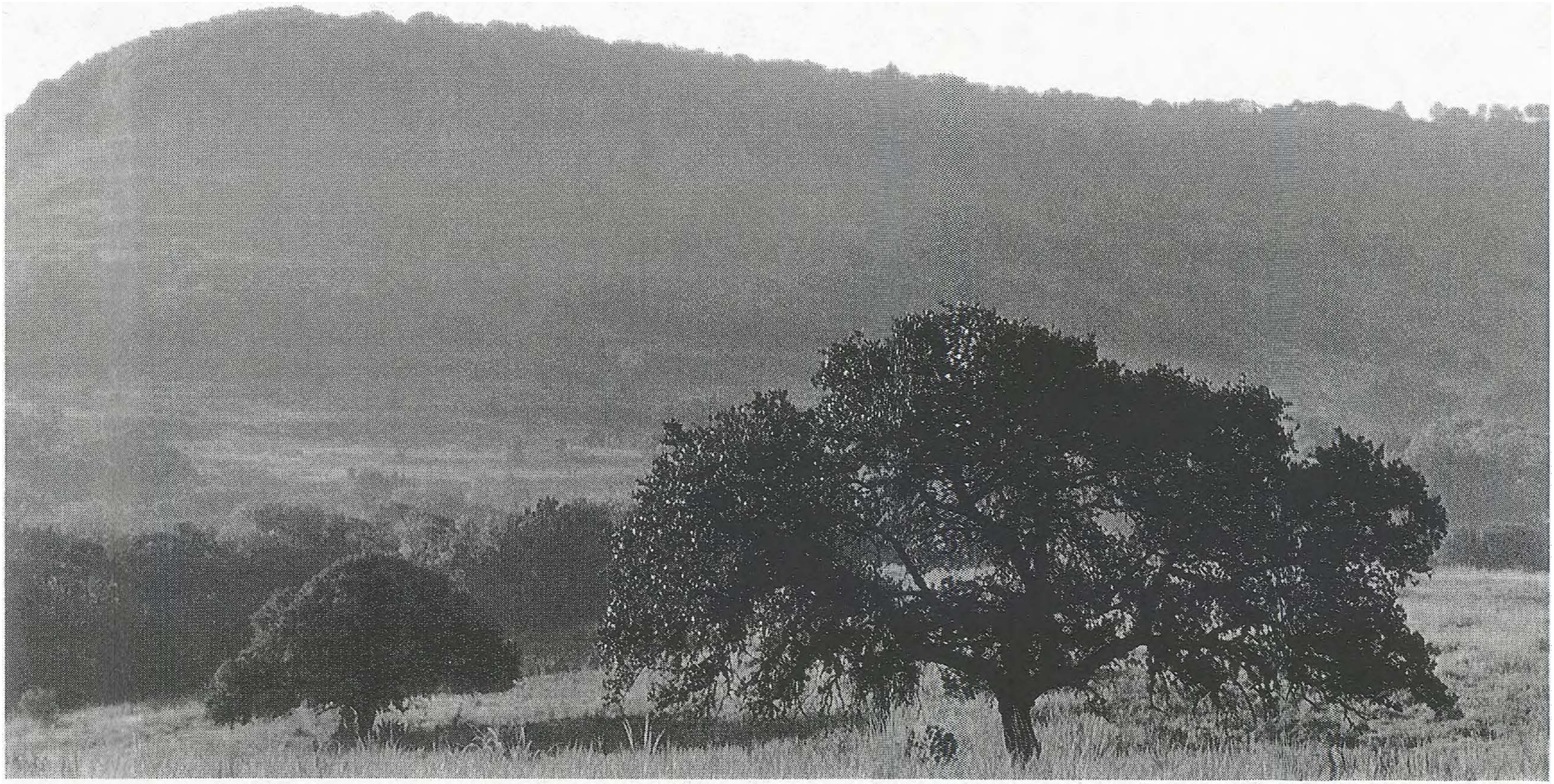
Figure 1. W.P. Webb's "institutional fault"—98th Meridian compared to 30-inch isohyet (modified from Larkin and Bomar, 1983; base map from Raiez, 1957).

Selah:
A Selection of Photographs

Robert W. Baumgardner, Jr.

If it form the one landscape that we, the inconstant ones,
Are consistently homesick for, this is chiefly
Because it dissolves in water. Mark these rounded slopes
With their surface fragrance of thyme and, beneath,
A secret system of caves and conduits; hear the springs
That spurt out everywhere with a chuckle,
Each filling a private pool for its fish and carving
Its own little ravine whose cliffs entertain
The butterfly and the lizard . . .

W. H. Auden, *In Praise of Limestone*



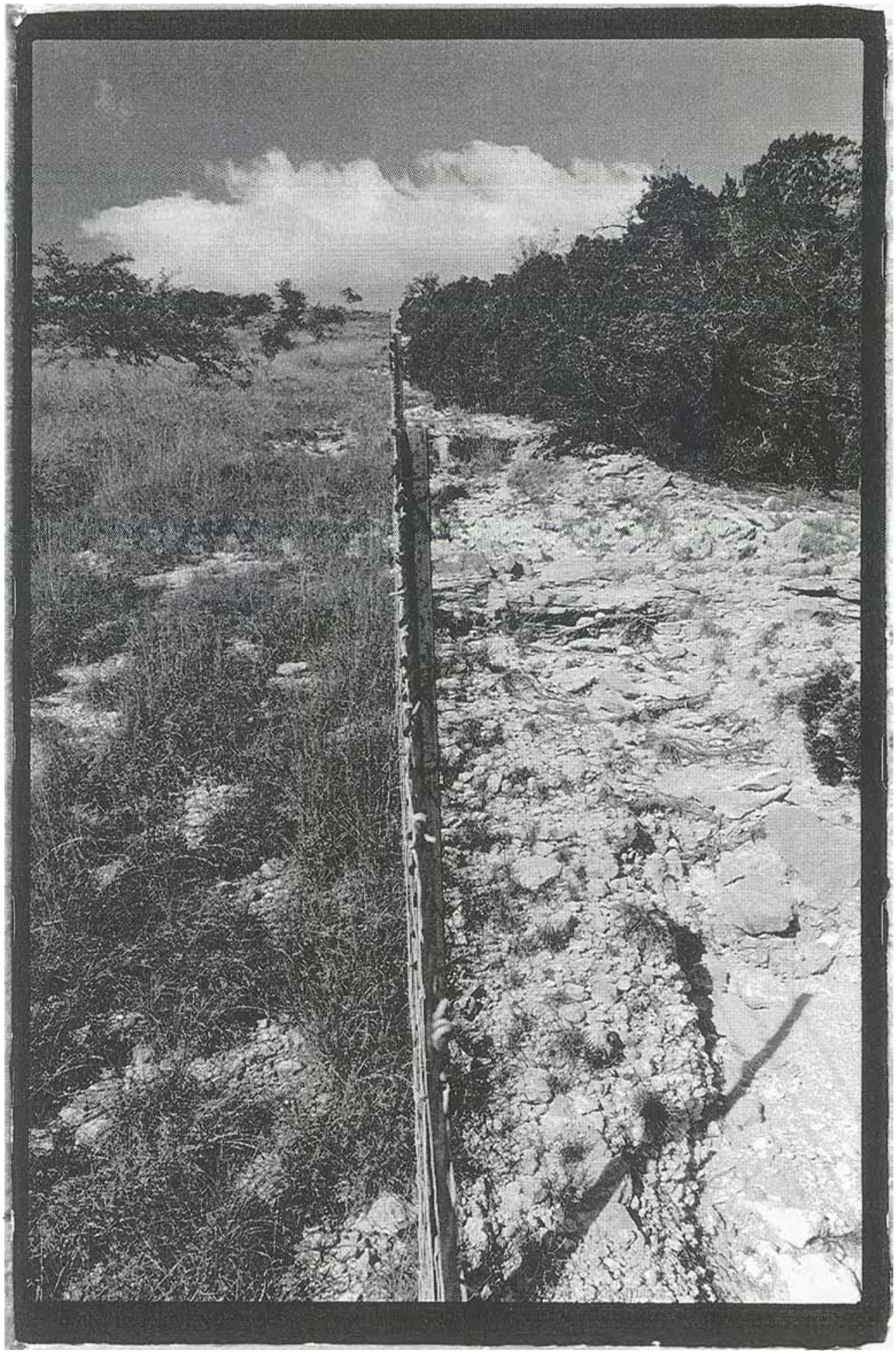
An oyster that went to bed x-million years ago,
tucked itself into a sand-bottom, yawned (so to speak),
and woke high in the Grand Canyon of the Colorado.

If I am not here for breakfast, geologize at will.

John Ciardi, *Goodnight*

. . . Finally even cedar came, cedar that can grow in the driest, thinnest soil, cedar whose fierce, aggressive roots are strong enough to rip through rock to find moisture, and which therefore can grow where there is *no* soil—cedar that grows so fast that it seems to gobble up the ground. . .

Robert A. Caro, *The Path to Power*



Oryx (*o*·riks). [a. L. *oryx* (acc. *orygem*), a. Gr. orux, orug (1) a pickax, (2) a kind of antelope or gazelle, so called from its pointed horns.]

a. The name in ancient Greek and Latin for an antelope of northern Africa, perh. *Oryx leucoryx* or *O. beisa*. b. In *mod. Zool*., a genus of African antelopes, of large size, with long straight (or slightly curved) pointed horns in both sexes; an antelope of this genus. **1535** Coverdale Deut. xiv. 5 These are the Beestes which ye shal eate: Oxen, Shepe, Goates, Hert (hart*), Roo (gazelle*), Bugle (roebuck*), wylde goate, Vnicorne (ibex*), Origen (antelope*) and camelion (mountain-sheep*). **1601** Holland Pliny I 231 Of this kind be the Origes (oryxes), the only beast, as some thinke,. . that . . haue their haire growing contrariwise and turning toward the head.

The Oxford English Dictionary, 1979
*Revised Standard Version of *The Holy Bible*, 1953

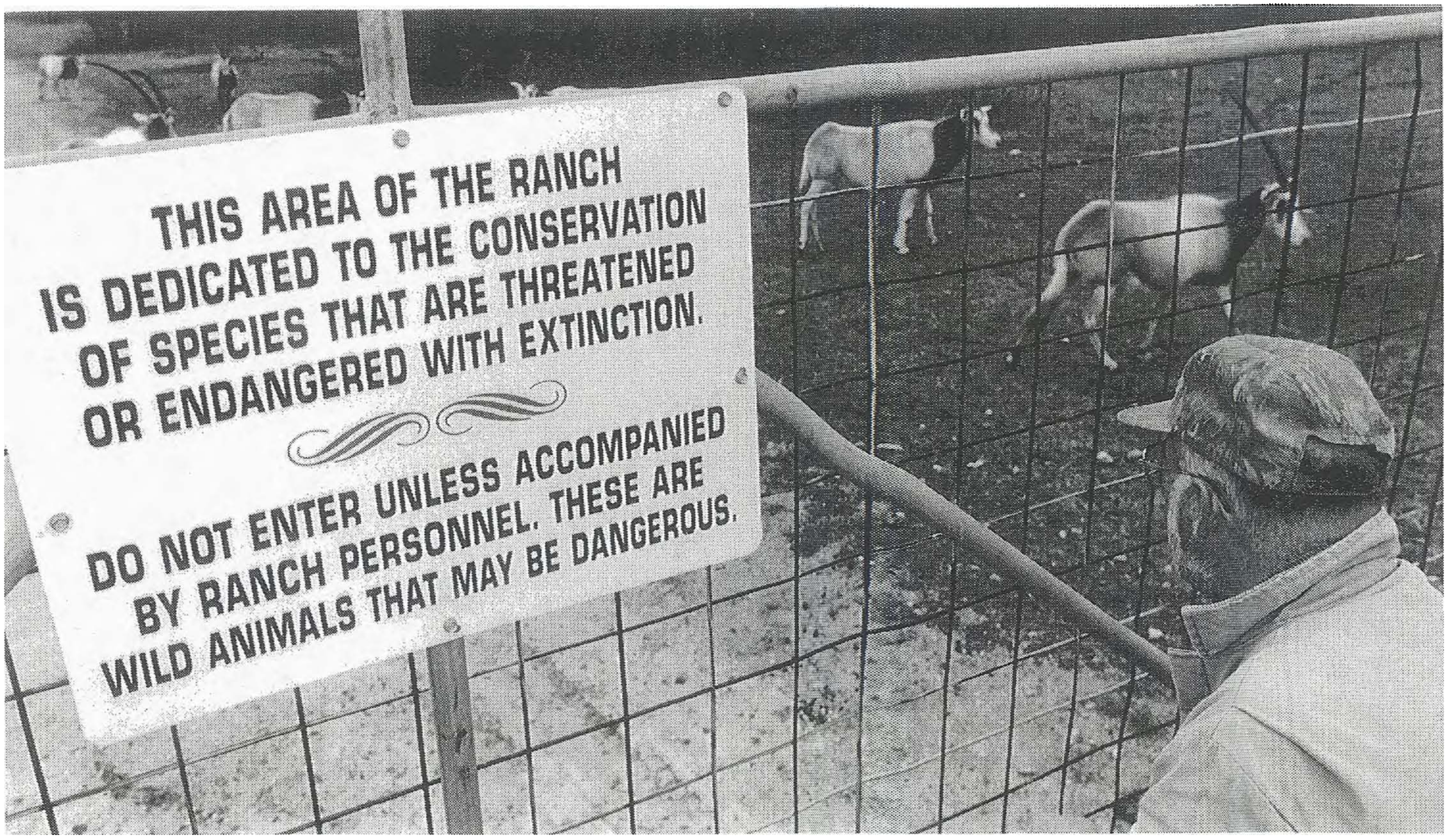
Auld Noah was at hame wi' them a',
The lion and the lamb,
Pair by pair they entered the Ark
And he took them as they cam'.

If twa o' ilka beist there is
Into this room sud come,
Wad I cud welcome them like him,
And no' staun' gowpin' dumb!

Be chief wi' them and they wi' me
And a' wi ane anither
As Noah and his couples were
There in the Ark thegither.

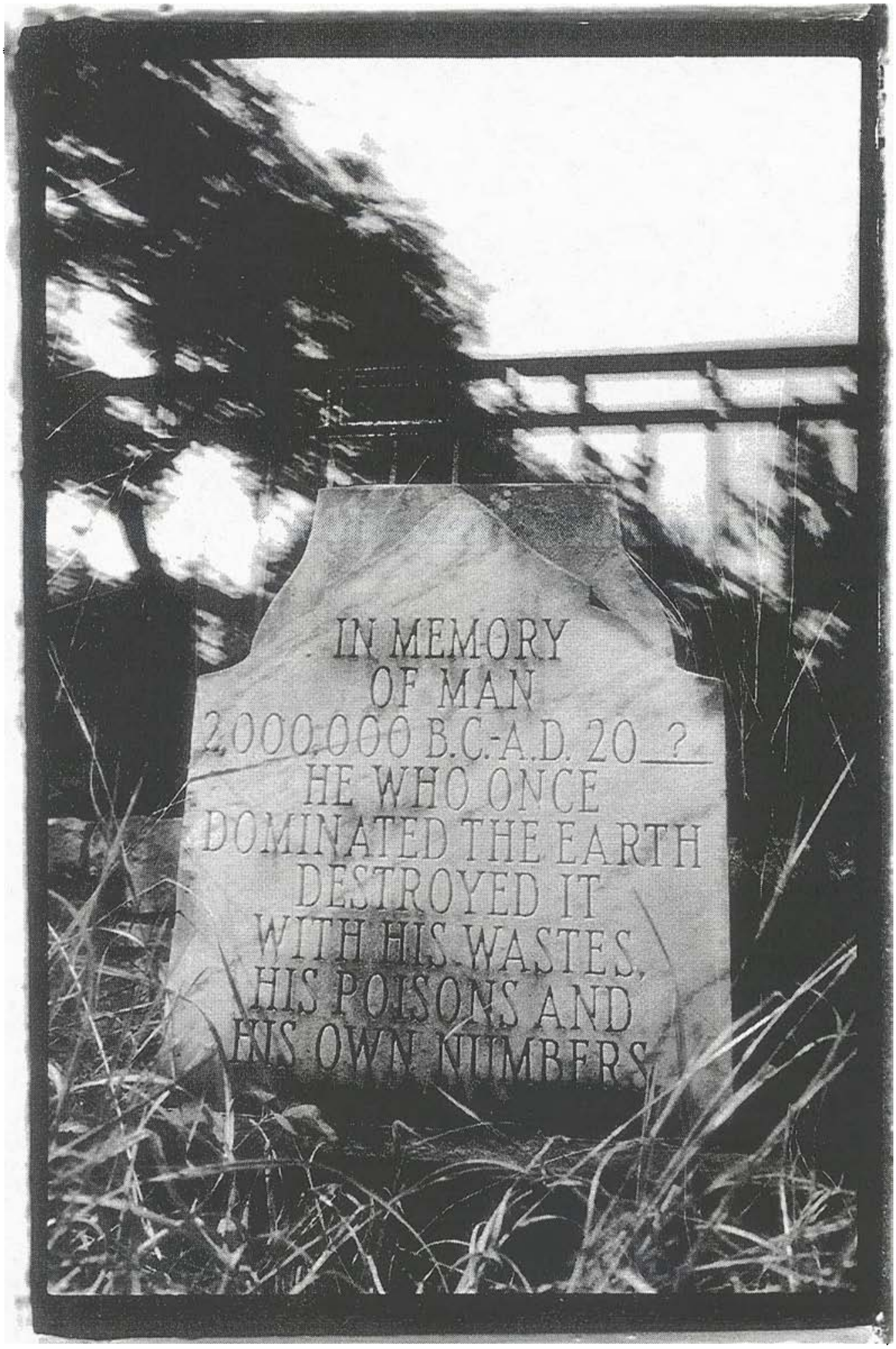
It's fain I'd mell wi' tiger and tit,
Wi' elephant and eel,
But noo-a-days e'en wi' ain's se
At hame it's hard to feel.

Hugh MacDiarmid, *Parley of Beasts*


THIS AREA OF THE RANCH
IS DEDICATED TO THE CONSERVATION
OF SPECIES THAT ARE THREATENED
OR ENDANGERED WITH EXTINCTION.
DO NOT ENTER UNLESS ACCOMPANIED
BY RANCH PERSONNEL. THESE ARE
WILD ANIMALS THAT MAY BE DANGEROUS.

. . . We are the offspring of history, and must establish our own paths in this most diverse and interesting of conceivable universes—one indifferent to our suffering, and therefore offering us maximum freedom to thrive, or to fail, in our own chosen way.

Stephen Jay Gould, *Wonderful Life*


IN MEMORY
OF MAN
2,000,000 B.C.-A.D. 20__?__
HE WHO ONCE
DOMINATED THE EARTH
DESTROYED IT
WITH HIS WASTES,
HIS POISONS AND
HIS OWN NUMBERS

Dramatic Short-Term Climatic Fluctuations and Their Impact on the Land—A Personal Perspective

Glen L. Evans

INTRODUCTION

Geologists, being familiar with the natural work of wind and water, generally regard erosion and deposition as the ongoing processes which ultimately culminate in tangible documents of earth history in the form of mappable rock units. These processes, however, are also involved in the creation of various other natural features which are less familiar, less definable and less durable than the rock units, but are in one way or another, of immense importance to the living world. Some of such weather-related phenomena are the subject of this paper.

DROUGHTS AND FLOODS

From the beginning of official weather recording, the average annual rainfall in the contiguous forty-eight states has hovered around 30 inches, and the wettest of all those years was only about 10% wetter than the driest. This tells us that in any given year, deficient rainfall in some parts of the country is approximately counterbalanced by surplus rain in other parts.

The accompanying rainfall charts from several physiographic regions of western Texas clearly reveal such significant information as the strongly fluctuating character of rainfall on the Edwards Plateau, especially along its eastern and western margins (figs. 1, 2, and 3). They also reveal the periodic recurrence of multi-year drouth and pluvial events even in regions of very different rainfall averages.

They cannot tell us, however, how much of any very wet year's rain came down in destructive gully-making torrents, or how much of a dry year's paltry offering was further negated by the thirsty dry winds.

What may have been the most devastating drouth of this century occurred during the 1930's decade. What made it so, however was not the usual serious deficiency of rain, but the seemingly ceaseless strong hot winds that drew moisture from every animate and inanimate source they touched. None of the rainfall charts I have made or seen give any indication of the momentous impact of that climatic interval, yet virtually all of them show it was followed by a prominent multi-year pluvial interval.

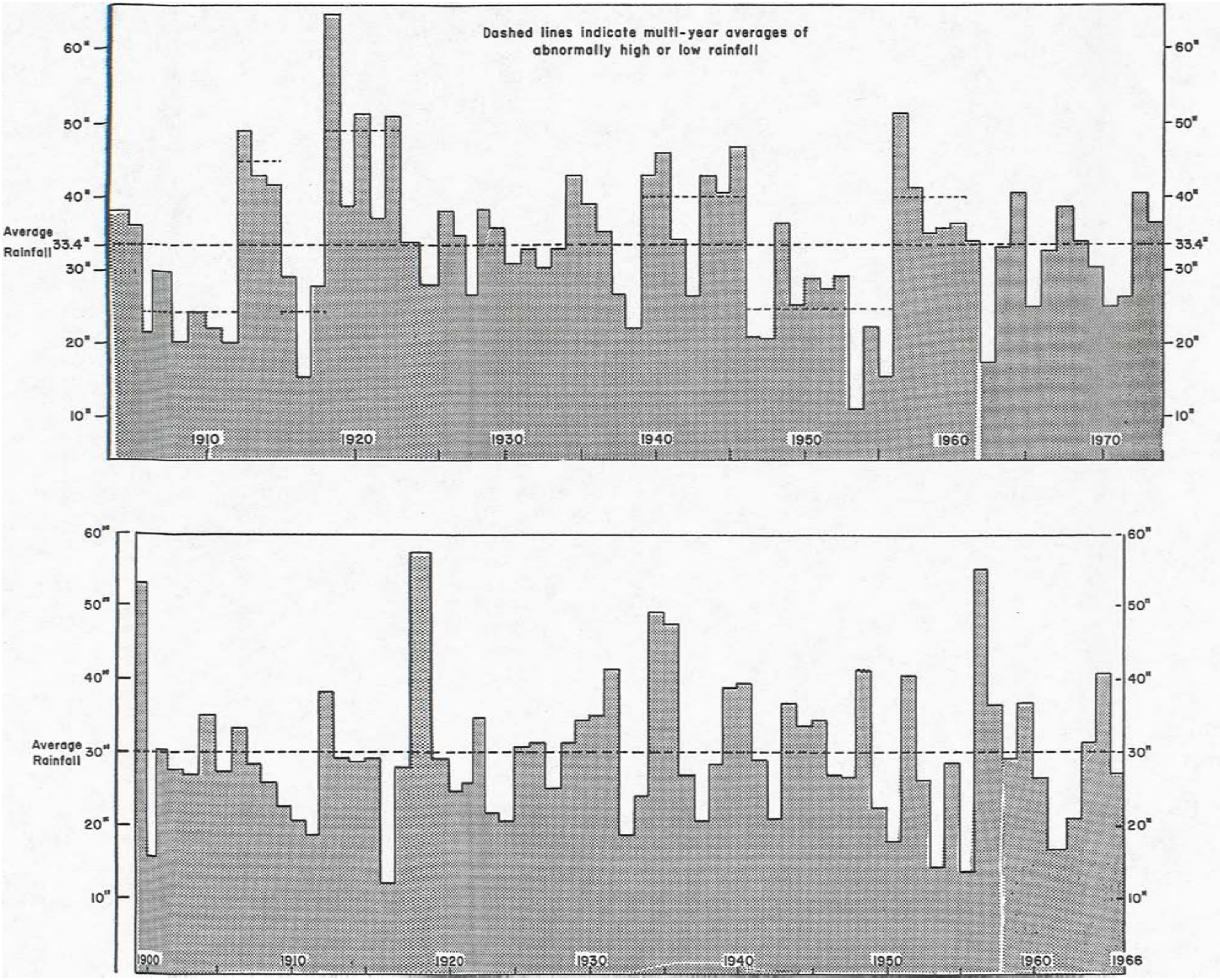


Figure 1. Long-term annual rainfall (in inches) for Austin (1903-1974—upper chart) and for Kerrville (1899-1966—lower chart).

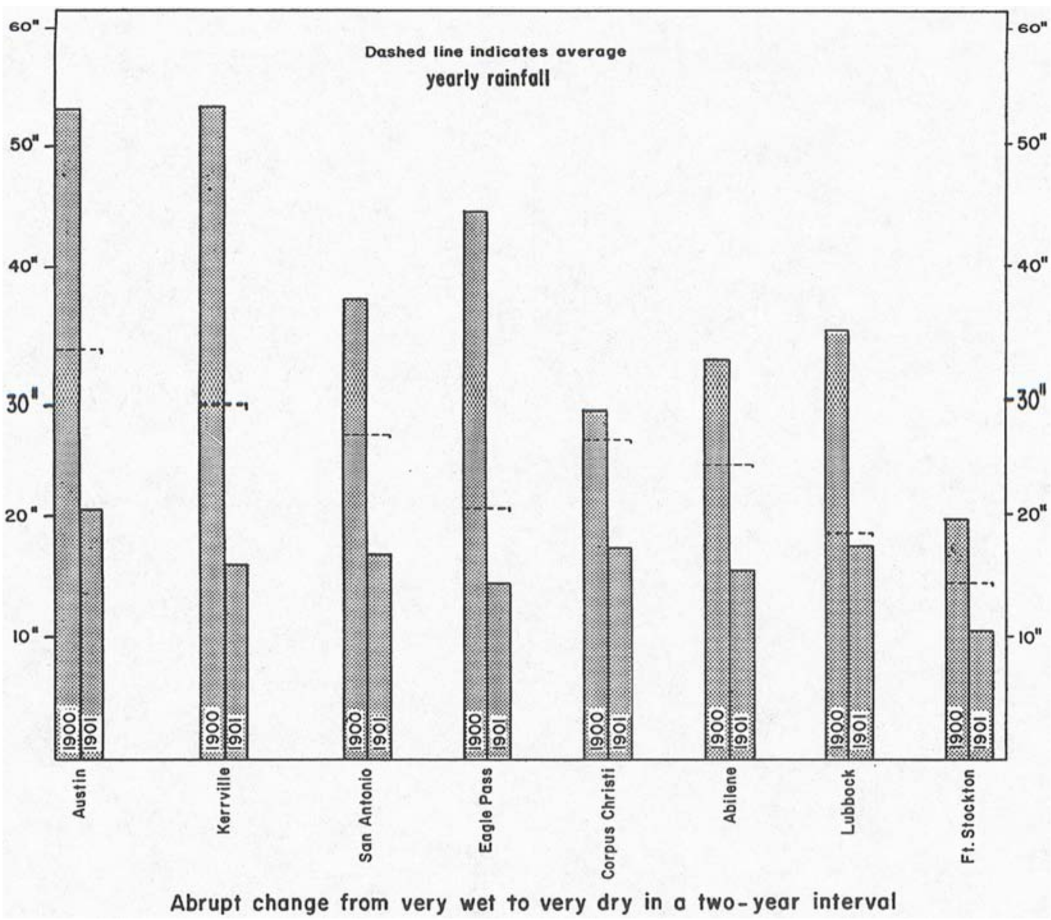


Figure 2. Annual rainfall (in inches), 1900-1901, at selected stations in Texas; note abrupt change from very wet to very dry in a two-year interval.

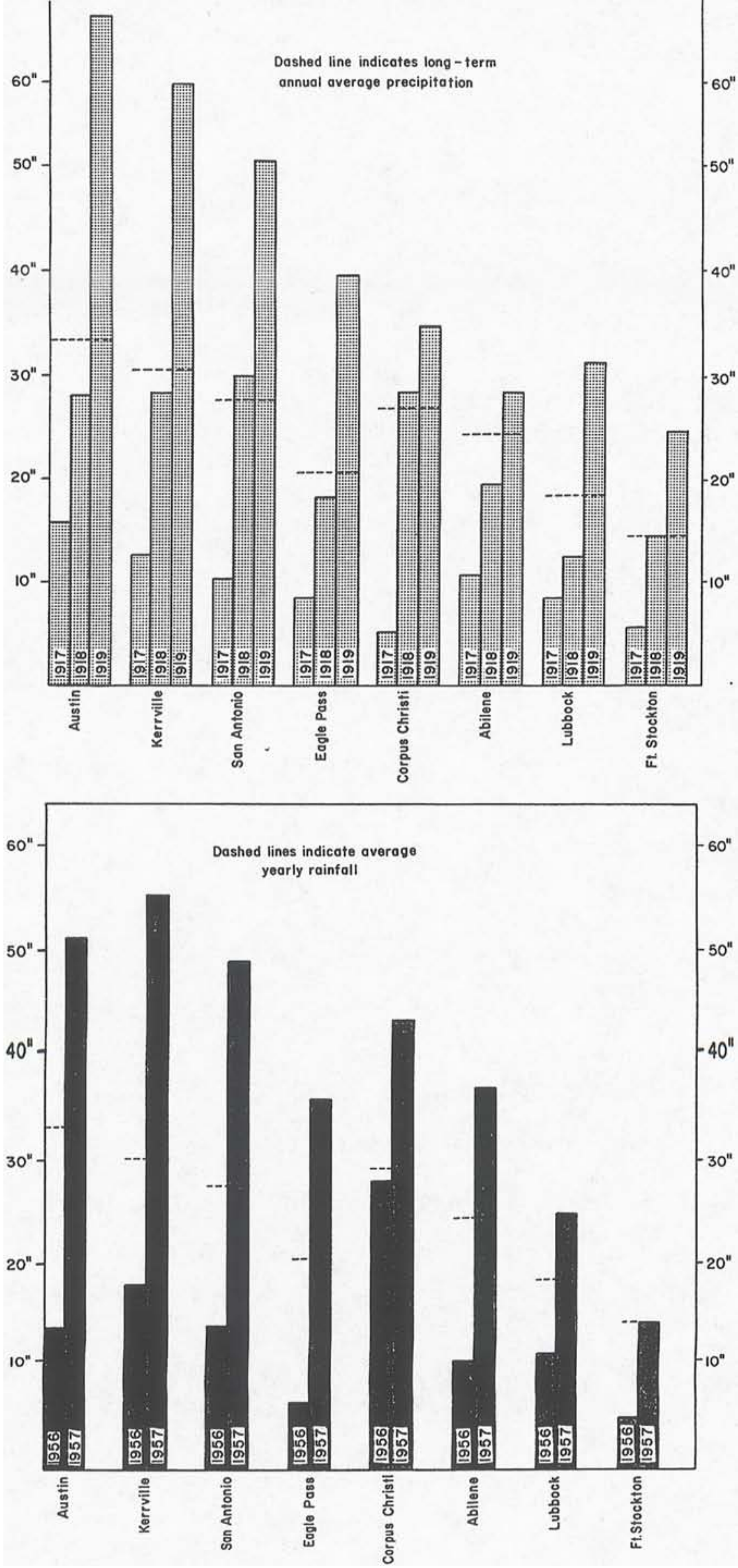


Figure 3. Annual rainfall (in inches), 1917-1919 (upper chart) and 1956-1957 (lower chart), at selected stations in Texas; note abrupt change from very to dry very wet during these intervals.

By contrast, the later mid-century drouth was characterized by seven continuous years of markedly sub-normal rainfall rather than by fluctuating wet and dry intervals, and its accompanying hot dry winds were less frequent and less devastating; but it, too, was abruptly terminated by a prominent multi-year pluvial interval. (Perhaps these modern recurring climatic events are recapitulating the glacial-interglacial sequence of Pleistocene time?)

Severe local rainstorms and consequent destructive flooding also occur during major drouths, but in quite isolated parts of the otherwise drouth-stricken regions. During the Dust Bowl drouth of the 1930's for instance, one such storm created the record flood on the Colorado River that completely inundated its Congress Avenue Bridge in Austin. During the some drouth, another violent local storm in southwest Texas precipated a great flood on the Devil's River, the largest flood ever recorded for a river of its drainage area. It swept away a large segment of one of the river's fertile alluvial terraces—along with the fine native pecan grove that had been growing on it for at least 100 years—and this, no doubt, was only a very small part of its total destructive erosion.

A number of such local flood-making events also occurred in Texas during the later mid-century drouth. Perhaps the most impressive of these occurred on the Rio Grande shortly after completion of the International Falcon Dam. On the basis of the river's average annual volume of water passing that point, it was reasonably estimated that the huge reservoir behind the dam would be filled in the course of several years. A short time later, however, the reservoir was filled to its spillway by a single massive flood, precipitated by a terrific local rainstorm some distance upstream from it.

Much of the enormous amount of sediment carried in to the reservoir from its storm-eroded sources was recently exposed in the form of drying mud when the impounded water was drawn down to a very low level. Under normal conditions much of that sediment would have been deposited from slackened over-bank flood water on the flat surfaces of bordering river terraces, thus adding another layer of raw material for conversion into their already rich alluvial soil. The swifter channel current would have carried most of its load on to the Gulf of Mexico to do its part in delta construction, and perhaps to provide some nutrients for certain kinds of sea life.

LIMESTONE CAVERNS

In many of the limestone caverns of the Edwards Plateau, rows of stalactites are seen along almost invisible cracks in the ceiling rocks. They testify to the fact that they had been formed by seeping water that had somehow found its way down from the surface and that, in doing so, it had leached out and enlarged its passageways by at least as much as the total mass of its icicle shaped cave formations. Such unseen cracks, and the many other kinds of mechanical and solution openings in the rock, perform an essential function in the plateau's ecology (fig. 4).

At some time during the second half of the 19th Century and at what was later to become an important geological locality some twenty-five miles north of San Antonio and the Edwards Plateau, a heavy rain saturated a rocky soil and carried some of it into an open crack in the

Figure 4. Rectilinear joints in Glen Rose Limestone along tributary of Sabinal River southeast of Utopia, Texas.

underlying limestone. A root from a healthy young live oak growing nearby probed its way into the crack and gradually spread it wider. From there, during following decades, it gradually worked its way downward through tortuous twists and turns in bedrock openings to a source of permanent moisture, which would help secure the tree's survival.

This was one of the oaks growing near the Friesenhahn Cave when we began our excavations there in 1949. During a long interval of late Pleistocene time, the cave had a large inclined opening to the surface through which it had accumulated a considerable thickness of soil washed into it by heavy rains. It also accumulated a rich store of fossil bones representing more than forty genera of vertebrate animals then living in that vicinity. Then the opening sealed itself off from the surface, as all such cave openings eventually do. This kept the fossils securely entombed for thousands of years before the modern entrance was created, when a vertical sink hole broke through the cave roof.

While collecting fossil bones from the cave fill, I exposed several vertical feet of its previously buried limestone wall and encountered what may well have been that probing root of the live oak now standing a little way north and about thirty-two feet above it. The root was considerably flattened where it emerged from a bedding plane in the limestone, but resumed its normal roundness a short way out in the fill. It must have found that probing into the soft fossil soil was a comparatively simple matter, for without changing direction or altering its shape, it went into one eye socket and out the other of a rare fossil skull from the extinct saber toothed cat, *Dinobastis Serus.* The root had grown to about an inch and a half in diameter, completely filling the eye sockets, so we had to saw it off on both sides in order to collect the skull intact with the root segment still within it.

Though it never occurred to me at that time, if no other entrance had formed and the cave had remained permanently sealed, that root and perhaps others from the same tree could have found in it a virtually inexhaustible source of nutrient and moisture. If so, the parent tree might have survived and prospered for who knows how many centuries after less fortunate surrounding oaks had perished. Here and there on the plateau still stand individual noble live oaks which appear several centuries older than the surrounding liveoaks. Perhaps some of the roots of these old giants are tapped into some similar body of buried soil.

EARTH CRACKS

Dry earth cracks, especially those in areas of tight clay-rich soil, seemingly continue to widen and deepen until the very end of the drouth that made them. Once, while making a topographic map of an area surrounding the Odessa Meteor Craters, I encountered a great number of gaping cracks in what was to be the final stage of their development—for this was shortly before the end of the dreadful Dust Bowl drouth. I noticed that range cattle abandoned trails that passed through the worst of these areas for ground that offered less precarious footing, but thought no more about the cracks at that time. A little later on, however, I was to witness an unforgettable natural event that demonstrated the essential role such cracks can play in revitalizing a rain starved land.

It so happened that when the drouth-breaking rainstorm came roaring in during the pre-dawn hours of that eventful day, I was staying at the site and sharing a very strong army tent with Mr. Ray Miller, the project manager. Even so, the storm struck with such force that we were by no means certain that the tent could withstand the terrific pummeling it was taking. It seemed to be trying to make up for all those rains that had failed to come; in any case, more rain fell during the next six hours than had fallen there during the previous two years. It fell in sheets, faster than the land about us could soak it up or shed it; so when we looked out upon it at daybreak our tent seemed to be floating in the shallow lake.

At about that time we became aware of a pervasive rumbling sound which neither of us could identify, and despite the drumming of rain on the tent, the noise seemed to be growing louder as time went on. It grew louder still when I later went out in the rain to have a look at a local depressed area I had mapped, to ascertain whether it now contained a pond corresponding to its mapped dimensions. Having satisfied myself that such a pond was indeed in place (though now overflowing from its lower rim the excess sheet wash pouring into it from the other side) I headed for a nearby area of dry earth cracks and the continuous rumbling noise now coming from that direction.

To say that I wasn't prepared for what I observed during the next few hours would be a gross understatement, for that was, indeed, one of the most fascinating and edifying natural history experiences of my life. Up to that time, I must have supposed that the cracks might be some eight or ten, possibly even as much as fifteen feet deep; and that now—like my pond—they would be full of water and overflowing with sheetwash. Instead, however, they were now brilliantly delineated from end to end with a continuous row of noisily bursting bubbles. It was some time later before I realized the full significance of what I was seeing and hearing. A considerable part of the slow moving sheet wash, up to ankle deep in places, was still pouring into those cracks against the resistance of rising air bubbles being displaced by it from underground cavities.

All of the major cracks examined in the general area were still bubbling furiously and taking in water at their maximum capacity. Clearly this had been going on since the rumbling began several hours earlier. Some small part of that water was doubtlessly soaking laterally into the soil, but most, perhaps as much as several acre feet of it, was replenishing much deeper bedrock cavities and the depleted regional aquifer.

The first of this sheet wash to enter those cracks had probably been decidedly murky with the ubiquitous dust that had settled on the land, but now it was almost clear, indicating that it was here causing very little erosion. A little way to the west, however, erosion was visibly taking place on the slopes of a large playa basin where the cow trails leading into it were now serving as energetic rivulets of muddy water.

Seeing and hearing the turbulent transfer of volumes of surface water through those earth crack conduits into open spaces in the bedrock down below was for me a marvelous revelation. It wasn't the only event to marvel at on that particular day, however, for presently spade-foot toads began to emerge along with the bubbles. They kept on coming and coming until what must have been thousands of them were splashing about in an area of less than two acres. By noon when the rain had almost ceased, the chorus of amorous toad song completely drowned out the decreasing rumble of descending water. It seems likely that those toads, and a lot of tiger salamanders which appeared a little later, were routed from deep and permanently moist hibernation niches, for in all our excavations thereabouts, we had never found a single individual of either species.

The rumbling and chorusing of this revitalizing land and its amphibians eventually ceased completely; and by evening of the following day, the swollen earth had so completely healed her gaping cracks as to leave no visible trace of where they had been.

DUST

As most observers of the land now realize, I suppose, the same rainstorms that wash away valuable soil also recharge our indispensable domestic and industrial water supplies in storages ranging from stock water tanks to major reservoirs. Not many of the same observers, however, could identify such compensating virtue from the suffocating dust storms generated by wind erosion during times of serious drouth. . .

On several occasions during the later part of the Dust Bowl drouth, I did some geologizing and fossil-hunting in the Monahans Dune Field of western Texas. There, even during lulls in the characteristic hot dry winds of that time and place, the pervasive dust made itself evident by irritating my eyelids and respiratory tract and adding a gritty texture to the inside of my shirt collar and to my midday sandwich. The significant fact that a great deal more of it must have been settling on and into the porous sand all about me somehow escaped my notice. So, of course, the possibility that the dust might contain a substantial amount of fertile organic matter also never occurred to me.

A few days after having witnessed the great rainstorm at the Odessa Meteor Crater, I made another visit to the Monahans Dunes—and found them miraculously transformed into an unbelievably beautiful garden of wildflowers. They grew luxuriantly on the windward slopes of living dunes as well as on the thousands of acres of partially stabilized sand thereabouts. It was a marvelous aesthetic experience for me, but it left me mystified. It hadn't occurred to me that those active dunes would be capable of sprouting a seed, no matter how wet the sand might be; nor did I realize that dust storms were capable of bringing in millions of viable seeds from flowers that had once made deserts bloom somewhere out in the west.

I had been in a number of those bad dust storms, including the one shown in the accompanying photography, after it had entered the Texas Panhandle and turned a cloudless mid-afternoon into a suffocating likeness of a cloudy night (fig. 5). Like almost everyone else, however, about all I learned about them was the various kinds of negative impact they were having on people, livestock and certain kinds of wildlife. I became acutely aware, for instance, that health-threatening quantities of dust from these storms invariably seeped into the most tightly sealed rooms of homes and public buildings alike, and settled impartially on every surface exposed to the touch of the air that carried it in.

Several of the incredibly large dust clouds of the "Dirty Thirties" rolled eastward out of their source in the heart of the Dust Bowl with seemingly self-generated energy, for they

Figure 5. Dust storm over Boise City, Oklahoma, c. 1937; photo by W.M. Baker.

continued all the way to the eastern seaboard while shedding enormous quantities of dust. At least one of these storms left a layer of its dust on the deck of a ship some 260 miles out in the Atlantic Ocean.

Perhaps preoccupation with dust, indoors and out, prevented those of us being afflicted by it from recognizing its geological and ecological significance. In my case, at least, it seemed a national disaster with no perceptible compensating benefits.

The dust which was being deposited in all manner of visible openings in rock and soil would eventually make them more hospitable for various seeds and roots—but I didn't know that. It formed dead gray coatings on grass, trees and other vegetation that set you into paroxysms of sneezing when you brushed against them. It wasn't really as destructive to plants as it sometimes appeared to be; in fact, when later rains would wash the dust from them and into the soil, it would become the invigorating element that set them off into healthy new growth—but I didn't yet know that, either!

In conclusion it should be noted that the causes and consequences of widespread strongly contrasting weather events must remain in part speculative, if only because each event varies in duration and intensity from place to place and each seems to be made up of an individualistic mix of weather factors. In my youth, certain old-timers speculated that "drouth rests the land," and seemed to consider this an adequate explanation for the sudden proliferation of growing things that commonly occur after the eventual drouth-breaking rain. This present day old-timer, however, speculates with considerable confidence that it is not its rest, but its drouth-engendered increments of fertilizing dust which brings on those wonderful proliferations.

Edwards Plateau and Hill Country—What's In a Name? What's On the Map?

C.M. Woodruff, Jr.

The Bamberger Ranch occupies two types of terrain: flat-topped plateau uplands and surrounding dissected hills (fig. 1). The plateau uplands comprise a narrow, crenelated extension of true Edwards Plateau, a tableland underlain by Edwards Limestone, exhibiting gently rolling slopes at relatively high elevations. Bordering the limestone tableland is typical Hill Country terrain, which at the boundary with the plateau uplands, consists of dissected drainageways and steep hillsides that descend from scarps underlain by Edwards Limestone. Substrate at the edge of the Hill Country/Edwards Plateau includes narrow belts of Comanche Peak and Walnut Formations, and extensive areas underlain by Glen Rose Limestone along the slope breaks below the Edwards Limestone cap (Barnes, 1967).

The Central Texas Hill Country comprises extensive areas west of the Balcones Escarpment underlain predominantly by Glen Rose Limestone. This dissected terrain is characterized by high drainage densities with headwater draws fed by myriad seeps and springs. Locally, large gravity springs drain the edges of the plateau uplands and feed the headwaters of major streams. The typical landforms of the Hill Country are conical or flat-topped hills and narrow, elongated ridges separated by drainageways of various dimensions. Typically, the hillsides are sculpted into stair-step terrain formed on the alternating hard and soft limestone, dolomite, and marly interbeds of the Glen Rose Limestone and the overlying Walnut/Comanche Peak Formations. The Hill Country consists chiefly of pre-Edwards Cretaceous bedrock west of the Balcones Escarpment and south of the Colorado River (Ferguson, 1989; Kier and others, 1977). Thus, it is distinguished from the Lampasas Cut Plain, which occupies similar bedrock north of the Colorado/Brazos drainage divide (Woodruff, 1987). The Hill Country also includes extensive areas of downfaulted Edwards Limestone in the recharge zone of the Edwards aquifer, local outcrops of basal Cretaceous (pre-Glen Rose) strata, and inliers of pre-Cretaceous rocks that form the substrate beneath the Llano topographic basin.

In contrast, the Edwards Limestone is composed mainly of hard beds of limestone or dolomite interbedded in varying thicknesses. Although locally riven by dissolution, the Edwards Limestone typically is resistant to erosion, and thus it stands out on the landscape as a prominent ledge-forming unit. In this way, it forms the cap for the Edwards Plateau. It resists stream dissection owing to hardness of substrate combined with the presence of dissolution cavities that collect surface waters and convey them into underground voids.

The two types of terrain--table land and dissected hills—represent two distinct geographic and hydrologic domains. The Plateau uplands represent the easternmost part of a vast karst limestone landscape, extending west of Blanco County for at least 225 miles to the margins of the High Plains. This limestone upland is typified by low stream density and thin, stony soils. Major caves occur locally, and these provide key permeability avenues for a major regional

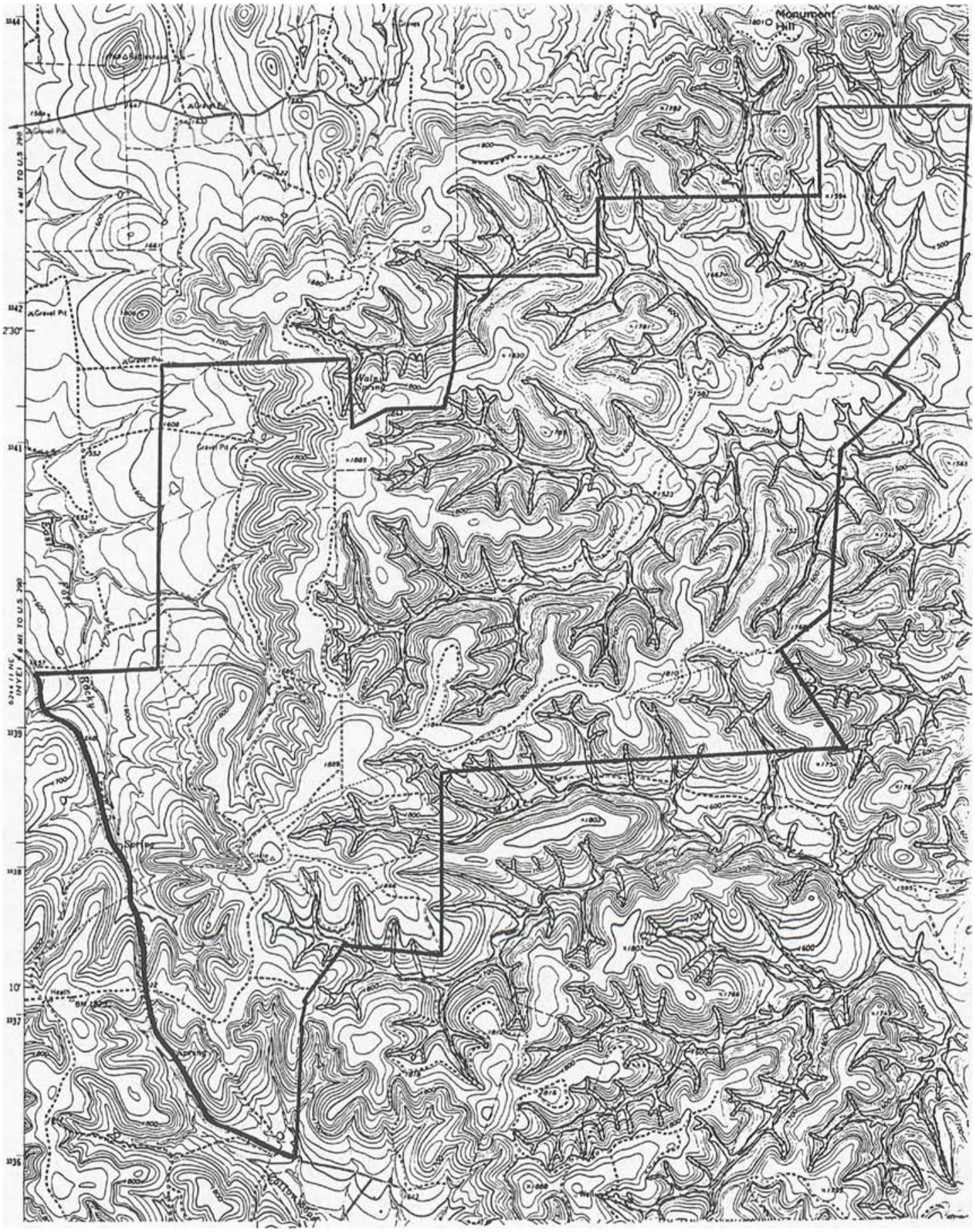


Figure 1. Topography of Bamberger Ranch, Blanco County, Texas (from Monument Hill Quadrangle, U.S. Geological Survey 7.5-minute topographic series; reduced to 1:48,000; contour interval = 20').

water-table aquifer. In contrast, the Hill Country consists of dissected terrain consisting of narrow uplands, extensive hillsides of varying steepness, and stream valleys ranging from narrow incised canyons to alluvial plains flanked by hilly uplands. Drainage densities are variable but typically high. Soils are locally thin or absent, and, except in areas of alluvial valley-fill, are almost everywhere stony. However, recent research has shown that upland soils of the Hill Country are locally thick, with high organic carbon contents—albeit still stony and thus not arable (see Wilding, this volume). Water-bearing units occur beneath this landscape, but groundwater is not collected and transmitted in a single water-bearing unit; instead, multiple stacked aquifers and aquatards occur across the hills. In general, groundwater quality and quantity are highly erratic within the upper parts of the Glen Rose section; lower in the section, groundwater attributes improve. The basal part of the Glen Rose Limestone interfingers with the Hensel Sand, which is the upper member of the Trinity Sands aquifers (see Ashworth, this volume).

Given the distinctive substrate, terrain, and hydrologic attributes of these physiographic regions, it is interesting to note that maps of regional landforms generally fail to distinguish them. In general, the Hill Country is regarded as a subprovince of the Edwards Plateau. This inclusion has a precedent that extends back 100 years to the earliest systematic geologic and geographic mapping efforts (Hill, 1900, 1901; Hill and Vaughan, 1896-97). It is still current today (Bureau of Economic Geology, 1996), although part of the rationale for grouping such disparate landform provinces is necessitated by scale: Simplification is essential when landforms within a state the size of Texas are depicted on a single page.

Robert Thomas Hill (1858-1841), a native of Nashville, Tennessee, who migrated to Comanche, Texas as a teenager and became fascinated with the local Cretaceous strata and landscapes in the area that he would later name the Lampasas Cut Plain. Later, as a graduate of Cornell University, he was the first geologist on the faculty of the nascent University of Texas, and subsequently, during a long tenure with the U.S. Geological Survey, he conducted the first systematic state-wide geologic surveys of Texas. Hill is widely recognized as the "Father of Texas Geology," and the names that he gave rock units and landforms live on today in our geologic lexicon and in the names of many physical regions of the state. Edwards Plateau and Lampasas Cut Plain are Hill's names; and so were Grand Prairie, Black Prairie, and the Cross Timbers, which he adopted from the vernacular. Regardless of origin, Hill's pioneering geographic work gave them all a formal definition and a degree of scientific precision. Interestingly, a vernacular Central Texas geographic name not used by Hill was the Hill Country; instead, the area that we call the Hill Country was denoted by Hill and Vaughan (1896-97) as part of the eroded "breaks of the plains" marking the margin of the Edwards Plateau along the Balcones Escarpment. In short, Hill included the dissected Hill Country as part of the larger Edwards Plateau Region, which in turn he defined as the easternmost subprovince of the Great Plains (fig 2).

Hill was well aware of the topographic differences encompassed within the vast Edwards Plateau Region. Several quotations clearly make the point:

> The term "plain," while applied to a region which is dominated by a conspicuous and persistent subhorizontal surface, is not always intended to

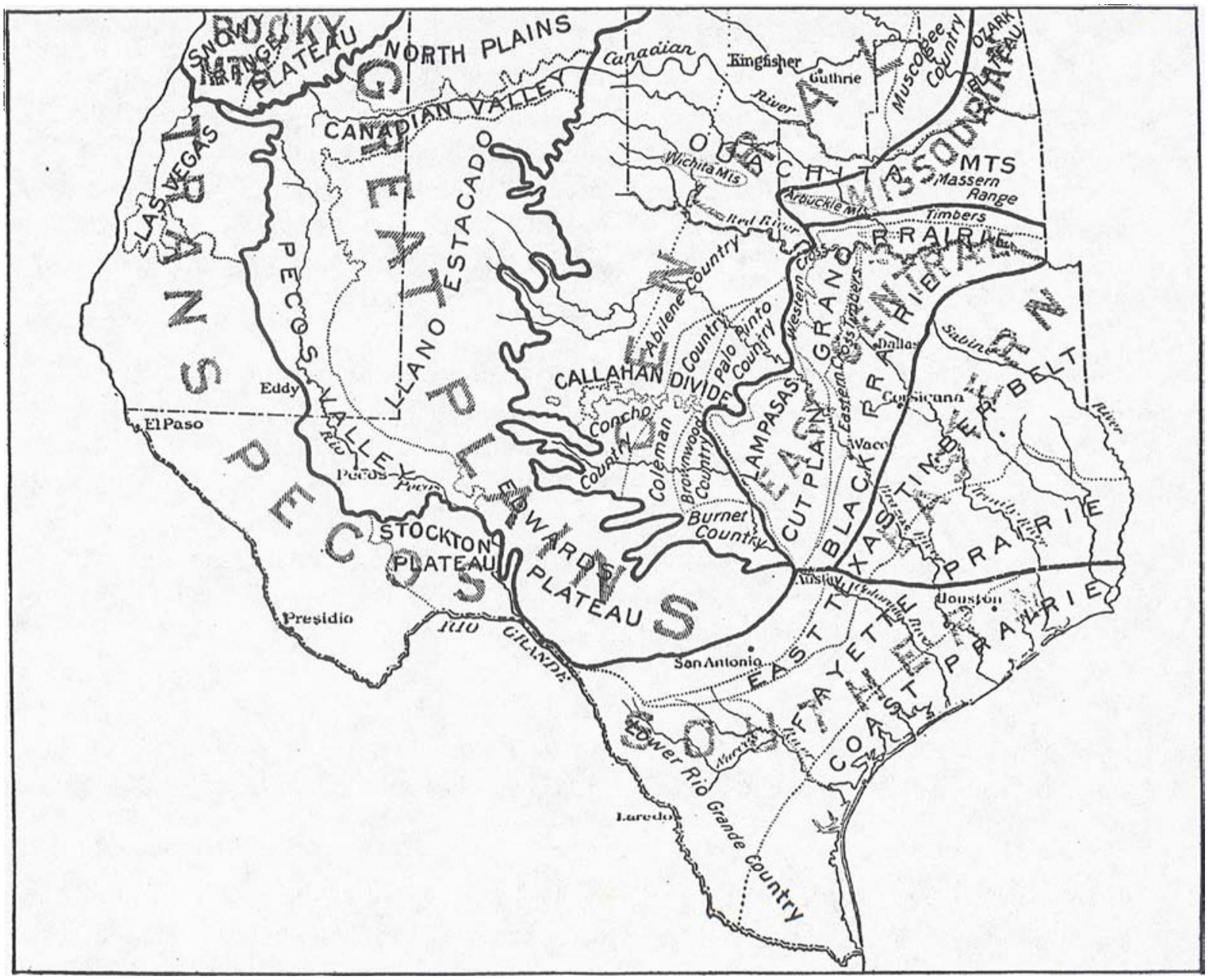


Figure 2. Edwards Plateau Region—one of the natural provinces of Texas (Hill, 1900).

> signify an unbroken monotonous physiographic feature absolutely without relief. It is true that some of the districts in the Texas region to which the term is applied are vast level stretches approximating as nearly as is found in nature a theoretical plane. But every plain, however level it may appear, presents within its area or as bordering phenomena some inequalities of configuration, such as valleys and rises, while some of the plains to be described are so rugged as to be locally classified as mountainous.
>
> (Hill, 1900, p. 5).

> The characteristics of the plateau are most strongly impressed on the observer who enters it from the Rio Grande Plain, for in crossing the Balcones line he experiences a sudden and complete change of scenery, with accompanying changes in floral, geologic, and cultural conditions. Instead of long, wide sweeps of prairie, void of sharp relief, he finds a region of steep canyons and sloping hillsides. The monotony of deep and dusty soils is replaced by alternate outcrops of cream-colored rocks and marls, occurring in long, continuous, and horizontal lines of stratification. A deciduous flora suddenly appears in the canyon valleys, replacing the semiarid chaparral. Rivers of flowing water, fringed by forests, replace the dry and stony stream ways of the plain, the mere trace of which is often lost in times of drought, and they now become fixed features of the landscape, boxed in with steep-walled canyons. Rugged evergreen hills succeed the long stretches of low undulating land with the yellow-brown adobe soils. Some of the beds of stratification composing the canyon walls are barren of foliage; others are occupied by the dark evergreen shrubs, juniper and Sophora, extending like garlands around the brows of the circular hills.
>
> (Hill and Vaughan, 1896-97, p. 205-206).

After noting that the Edwards Plateau region comprises three types of landform, the flat-topped summits, the breaks, and the stream ways, Hill gives a succinct and poetic description of the summit terrain, which I define as the Edwards Plateau, proper.

> The summit of the plateau is reached by ascending the long canyons of the streams and passing out upon it through their "draws" or *caletas*. Like that of the Llano Estacado, it is flat and void of constant-running streams. There are a few shallow, pondlike depressions or "sinks" which occasionally contain water immediately after rainfall. In general it is covered with a thick growth of nutritious grass and is without forest. Here and there, however, may be seen thick patches of scrub live oak, known as "shin oaks," growing in dense patches called "shinneries." For miles and miles the level, grass-covered plain stretches before the eye like a great sea, the view broken only at long intervals by the tall shaft of a rancher's windmill, rising like the sail of a lonely vessel on the level sea.
>
> (Hill and Vaughan, 1896-97, p. 206).

So it is that we see Hill's understanding of the distinction between the Edwards Plateau, as a nearly level upland surface and the deeply dissected Hill Country that cuts the Plateau upland along water courses draining to the Balcones Escarpment. The division is not shown on any of Hill's maps, however, and he does not use the name, Hill Country. The mapping of this boundary was likely constrained by what was, until recently, incomplete topographic map coverage across the region.

In recent years, regional physiographic maps (for example, Kier and others, 1977, and Ferguson (1986) have attempted to show the topographic break between the Edwards Plateau, proper, and the dissected Hill Country. But these small-scale maps are only an approximation. To be precisely drawn, large-scale maps are needed. The boundary is not identical to the geologic contact at the base of the Edwards Limestone; hence, geologic maps (such as the Geologic Atlas of Texas or Barnes [1992]) do not depict the limits of the Edwards Plateau. Instead, detailed resolution of topography is needed to distinguish the edge of the limestone tableland from the dissected terrain surrounding it. To accomplish this end, it is necessary to use 7.5-minute topographic quadrangle maps. This mapping has been done, at least for the southern margins of the Plateau/Hill Country lying within the Guadalupe, San Antonio, and Nueces River Basins. The work was conducted by the Bureau of Economic Geology during the early- to mid-1970s under contract to the Texas Water Development Board, with the purpose being to create an environmental geologic atlas of these watersheds to support water-resource planning for major aquifers within the region (for example, the Edwards and the Wilcox/Carrizo aquifers). Unfortunately, only a fraction of the region was eventually presented on published maps (Wermund and Gustavson, 1985 a-b). The published maps are at a regional scale (1:250,000), and owing to technical cartographic constraints, these maps are printed on a planimetric base; the absence of topography limits the ease with which these maps may be used in analyses of landforms. Nonetheless, landform delineations for the remainder of these watersheds do exist on 7.5-minute compilation maps on file at the Bureau of Economic Geology. Hence, precise delineations of Edwards Plateau upland and various landform units composing the Hill Country are mapped for these southern watersheds of the Edwards Plateau region. A partial elaboration of map unit characteristics is reported in a study of a test area in the Nueces Watershed (Wermund and others, 1974). Given the dramatically different hydrologic regimes between the plateau uplands and the dissected Hill Country, such mapping is needed for the Colorado and Rio Grande watersheds as well.

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The Influences of Structure on Landform Development in the Monument Hill Area, Central Texas

H. S. Nance

INTRODUCTION

Normal human perspective is limited by our size. Often it's hard to see the mountain range for the hill in the foreground, though a beautiful hill it may be. Following this theme, Hill Country landform development around Selah can be contemplated at more than one scale. At our normal perspective, we can classify the soils developed on different parts of hill slopes, or determine why the profiles of entire hill slopes vary. Generally we can readily make observations and measurements, or take samples at this scale. As our senses are calibrated we can make fairly accurate judgments of some parameters without the usual tools.

On the other hand, if we wish to consider the reason why Monument Hill (to the north of Selah, Fig. 1) is where it is, or why it looks different than the equally elevated areas to the west, then we are compelled to develop information with a regional perspective, and consider factors that we cannot directly observe. Regional data sets are generally compiled from numerous smaller-scale measurements and take the form of maps whose perspective is from extreme high altitude. It is from this perspective that we will consider the regional structure and landform development in the area around Selah.

EDWARDS LIMESTONE AND PLATEAU DISSECTION

The highest areas around Selah are capped by weather-resistant Edwards limestones of Early Cretaceous (Albian) age. They were originally deposited on broad shallow-marine platforms within the Western Interior Seaway as extensive layers of fine-grained carbonate sediment (mainly calcareous structures from marine organisms, and carbonate precipitates). Edwards limestones (which also include some beds of magnesium-rich dolostone) are now pervasively cemented to concrete-like hardness. The vast table land of the Edwards Plateau to the west of the Hill Country largely owes its geomorphic form to flat-lying, weather-resistant caps of Edwards limestones.

It will be later proposed that the Edwards may be systematically fractured. Hard limestone tends to fracture when stretched or bent. Fractures (faults or joints) often occur in somewhat regularly-spaced swarms and are highly directional. Multiple fracture sets, each with its characteristic modal direction, are often present. Orthogonal sets (two sets of fractures oriented at right angles to each other) are common. Fractures comprise zones of weakness in the rock and are convenient locations for dissolution and ice wedging, which increases fracture size.

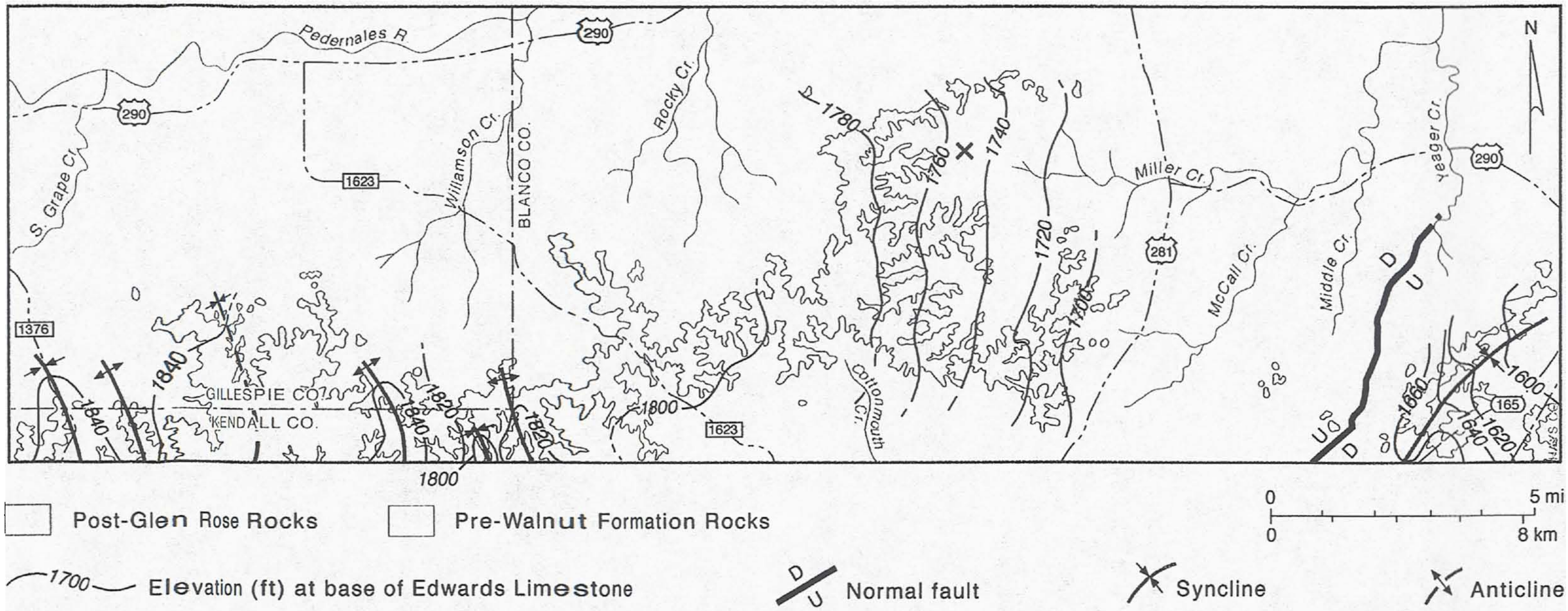

Figure 1. Map featuring the outcrop of post-Glen Rose Cretaceous rocks and structure contours on the base of the Edwards Formation, Stonewall, Hye, Monument Hill, and Yeager Creek quadrangles, Texas. Selah is in the vicinity marked X. Monument Hill is the question-mark shaped form to the north.

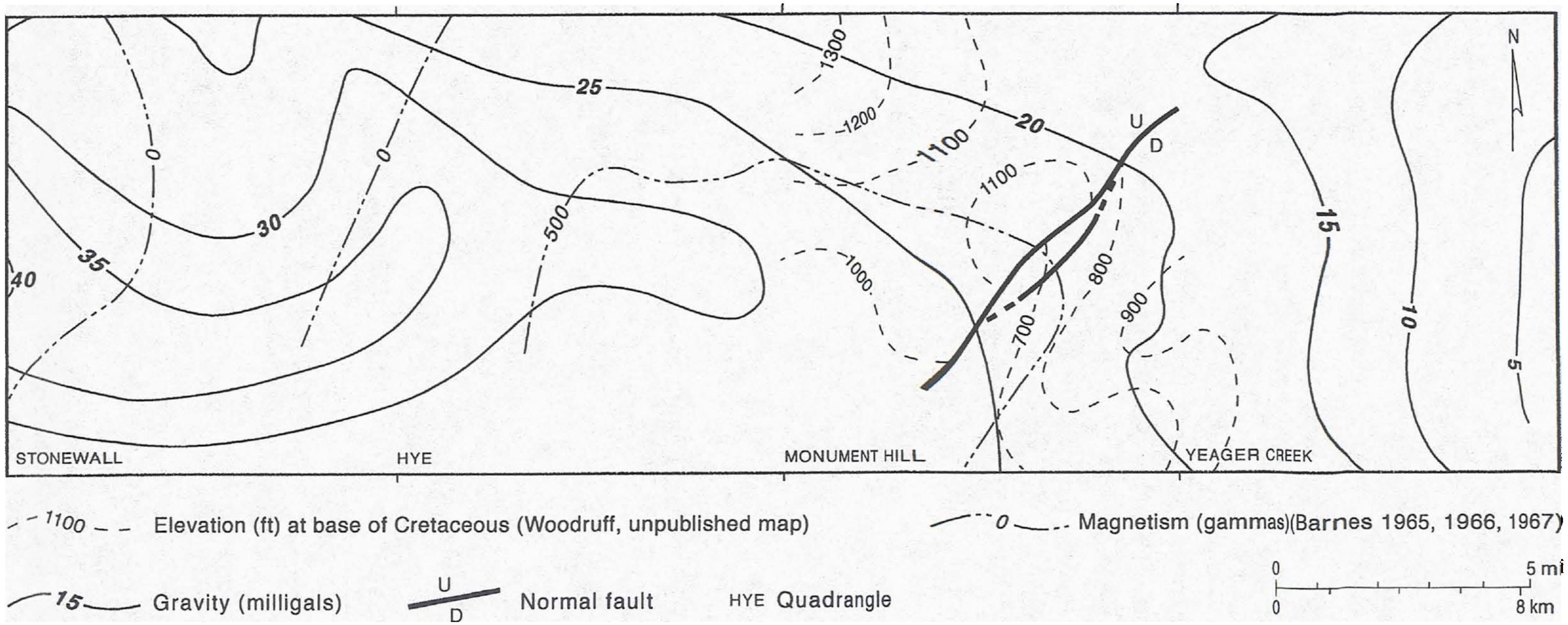

Figure 2. Subsurface data sets including gravity and magnetic surveys (Barnes 1965, 1966, and 1967), and a structure contour map on the Cretaceous subcrop (Monument Hill quadrangle only; Charles Woodruff, unpublished map).

Eventually surface flow may become focused in degraded fracture zones and add abrasion to the list of processes that promote incision.

Once the Edwards caprock is eroded, the underlying, overall less weather-resistant limestone-dominated Comanche Peak, Walnut, and Glen Rose Formations are exposed from above and deeply incised. This process causes dissection of the plateau. Monument Hill, north of the ranch, is an excellent example of complete dissection where beds (including Edwards caprock) were originally continuous between the hill and the ridge to the west. In time, the ridge will be dissected into additional hills whose alignment will reflect the trend of the original ridge.

In the immediate vicinity of breached Edwards caprock, steep walls are cut into the underlying rocks. Edwards caprock armors less weather-resistant beds beneath and limits lateral grading. Ultimately, the caprock recedes because its underlying support by subjacent softer limestone (marl) is compromised by undercutting. Cobble- to boulder-sized Edwards fragments detach from the caprock and then creep or roll down the slope. This process is expected to be more aggressive in previously fractured locations along the edge of the caprock. Eventually large fragments will fragment further, suffering some chemical reactions (including dissolution) along the way, and end up as numerous smaller grains swept away by flooding streams at the base of the slope. With renewed vigor, the process of undercutting continues back up on the fresh rock face.

REGIONAL PERSPECTIVE

With these materials and processes in mind, we move our perspective far above Selah to look at regional geologic patterns within which the ranch is physiographically but a small part. This perspective reveals the regional geologic underpinnings to which Selah owes its unique natural attributes.

The flat-topped areas within and around the ranch (Fig. 1) are continuous with or near a 45-mile-long ridge capped by Edwards limestone that extends due west from Selah to the headwaters of the Pedernales River. There, the ridge joins the main province of the Edwards Plateau. In fact, the ridge is physiographically transitional between the Edwards Plateau and the Hill Country, which is heavily dissected. In the Selah area, some of the high country is directly connected to the extensive ridge and has all the attributes of the Edwards Plateau, whereas isolated flat-topped hills (Monument Hill, for example) are erosional remnants and are classic Hill Country landforms.

What captures the imagination in the Monument Hill quadrangle (Fig. 1) are the exotic forms of the partially dissected ridges (capped by Edwards limestones) that stretch out finger-like to the northeast from the larger north-south ridge on the western margin of the quadrangle. However, in the adjacent Hye quadrangle to the west, similar finger-like ridges point to the northwest. Many ridges in both areas appear to be quite straight over several miles. Can we find a reason? Also, if most of the Edwards resides on narrow ridges, why is the map pattern in southeastern Stonewall quadrangle more pod-like?

The present focus is on the geomorphic influences of stratal attitude, or structure, of the Cretaceous rocks in the study area. In general, all the Cretaceous limestone beds in the area are parallel to each other, so a map on any one bed would reflect the attitude of all the other beds as well. The elevation (relative to mean sea level) at the base of the Edwards limestone is easily mappable from available geologic/topographic maps (Barnes 1965 1966, and 1967). This is additionally fortunate because the properties of Edwards limestones largely control initial erosion patterns that eventually turn Edwards Plateau into Hill Country. Less fortunate is the fact that today only a small area of Edwards limestone remains here as a thin veneer of armor atop more easily eroded subjacent limestones. Using the little remaining Edwards to interpret the form of the original expanse is the principal challenge.

STRUCTURE OF EDWARDS LIMESTONES

Cretaceous limestone beds in the area appear perfectly flat to the eye but are actually tilted locally in different directions and are slightly deformed (folded) into broad upwarps (anticlines) or downwarps (synclines) that are fractions of to several miles across (Fig. 1). The project area is composed of several structural subprovinces with regard to the Edwards. In the far east (Yeager Creek quadrangle), the Edwards is folded into a northeast-plunging syncline bounded on the northwest by a normal fault. A second subprovince is in Monument Hill and western Yeager Creek quadrangles. Beds in most of Monument Hill quadrangle dip to the east uniformly at about 20 feet/mile. Although only a few outcrops remain in western Yeager Creek quadrangle, they suggest that the original dip across the quadrangle to the northwest side of the fault was about 20 ft/mi there, as well. There is evidence that beds dip more to the north in the northern part of the Monument Hill quadrangle and beyond. In westernmost Monument Hill quadrangle beds flatten to rates of 5 ft/mi rise to the west. In the south part of the quadrangle, dips start to change to southeast. (Note that the long continuous ridge that crosses the area tends to parallel this change in structural trend). In Hye and Stonewall quadrangles, the Edwards is overall more horizontal, with an average change of elevation of only 5 feet/mile. Superimposed on this overall terrace-like structure are several smaller-scale southeast-plunging anticlines and synclines along the southwestern margin of the study area. The map area is still too small to see the entire structural picture but the impression is that the study area could be on a large southeast-plunging anticline.that has several smaller folds superimposed on it. The flatter areas west to Monument Hill quadrangle could be approaching the anticlinal crest.

CORRESPONDENCES BETWEEN LANDFORM AND STRUCTURE: A PROPOSED EXPLANATION

Edwards rocks are most abundant on the steeper structural slopes in Monument Hill quadrangle and (in pod-like form) in the large syncline in Stonewall quadrangle. These areas are connected by a very thin ridge, less than 0.25 miles across at many points. Also, ridges in Monument Hill quadrangle trend northeast while ridges in Hye and Stonewall quadrangles trend mainly northwest. The northwest-trending ridge that joins northeast-trending ridges in southern Monument Hill quadrangle is transitional between these areas.

These observations can be reconciled in a model where hard limestone beds with orthogonal fracture sets (oriented roughly northeast and northwest) are folded to their present attitude. On the broad crest of the Hye quadrangle anticline, the proposed northwest-trending fractures open as the upper surfaces of beds are stretched. The opened fractures areas focus weathering processes. The remaining northwest-trending ridges in the area suggest preferential erosion along similar directions. In the syncline in Stonewall quadrangle, however, fractures are more likely to be pinched shut in the pod-like Edwards outcrop because the upper surface of a sagging bed is laterally compressed. This condition may have limited weathering along fracture sets, thus precluding the exaggerated ridge development seen elsewhere. Similarly to the Stonewall example, the few surviving ridges of Edwards rock in southeastern Yeager Creek quadrangle are occupying a syncline.

Note that the northeast-trending ridges in Monument Hill quadrangle are at an angle to the structural dip. Given the persistence of Edwards limestones, we might expect streams to develop directly along the steepest structural slopes. Indeed, east-flowing Miller Creek does conform to expectations insofar as the attitude of Glen Rose strata probably parallels that of formerly occurring Edwards rock. However, its headwater tributaries trend northeast, parallel to the Edwards-capped canyon walls that define their courses. This deviation from the expected can be explained by preferential weathering along proposed northeast-trending fracture sets, which are roughly orthogonal to the proposed fracture sets important in explaining ridge orientation in Hye and Stonewall quadrangles. In Monument Hill, the surface of the anticline curves around to an orientation where the proposed northeast-trending fractures preferentially open. Prevalence of both northeast and northwest ridge trends in southern Monument Hill quadrangle indicates an area where both sets may be equally open to weathering.

The difference in structural gradients between Hye and Monument Hill quadrangles may explain why ridges remain on the anticlinal limb in Monument Hill quadrangle, while few ridges remain on the anticlinal crest in Hye quadrangle. The flat attitude of beds on the anticlinal crest limits runoff, thus allowing an opportunity for chemical and thermal weathering to affect both proposed fracture sets equally. Caprock may have been, on geologic time scales, simultaneously incised over the entire anticlinal crest. Thus, removal of materials may have been relatively uniform compared to areas where ridges survive to suggest dominance by incision along a preferred direction.

Higher runnoff rates afforded by the steeper dips in Monument Hill quadrangle may be more of a factor where it probably facilitates dissection through more aggressive vertical erosion of soft limestones (marls) beneath the Edwards. This process should proceed preferentially along fracture-weakened zones that are those most closely aligned with the slope.

Although a conclusion is preliminary, there does appear to be a relationship between subtle Cretaceous structures and landform development in the Hill Country around Selah. In this area, processes that are most likely to cause the subtle folding interpreted for the Cretaceous involve draping of the limestone over underlying structures, where the structural attitude of the Edwards approximates the shape of the underlying rock bodies.

Figure 2 presents three types of subsurface data sets for the project area. Gravity surveys show where rock bodies of lower or higher densities might be located. In our area, lowest gravity values often indicate the presence of granite, such as the Town Mountain granite exposed at Enchanted Rock Natural Area near Fredricksburg (Barnes, 1967). The east-west trending gravity high that crosses the area suggests that something denser than granite may underlie Monument Hill quadrangle, such as a mass of Packsaddle Schist (Barnes ,1967). Data point locations (not shown here) would allow contouring of the data to bring the gravity contours into more parallel attitude relative to local structural strike, but the significance of such potential correspondence will not be considered further at this time.

The magnetic survey suggests that the presence of iron-rich rocks within the magnetic high zone located in southern Monument Hill quadrangle might be caused by Precambrian Packsaddle Schist or possibly basic intrusions (Barnes, 1967). It's noteworthy that the magnetic high corresponds with the gravity high in Hye quadrangle and both lie beneath the southeastward extension of the Edwards anticlinal nose, while the magnetic low is closed around the prominent Edwards syncline in Stonewall quadrangle. Are these data related or only coincidental?

The structure on the top of the Ordovician-age Ellenburger Group (Charles Woodruff, unpublished map) shows an anticline in northwest Monument Hill quadrangle that plunges southeast into a northeast-striking normal fault. To the southeast on the down-side of the fault, the surface of the map unit may compose several southwest-plunging folds. Notably, the contour trends on all three subsurface data sets change direction in the vicinity of the fault shown in the Ellenburger rocks. This suggests that the gravitational and magnetic anomalies are related to rock bodies affected by or otherwise related to the fault. However, little compelling similarity between these data sets and Edwards structure is noted.

Another potential cause for local warping of the Edwards is the removal by dissolution of strata in underlying formations. Evaporites (variously water-soluble minerals deposited within carbonate sediment or as distinct beds in hypersaline lagoons) are found in the Glen Rose. Some of these materials might have dissolved as fresh water percolated through the Cretaceous section in the period since its uplift in the Tertiary. Alternatively, systematic dissolution of limestone in the rocks below the Edwards could create space to cause minor warping. Field investigations could test the viability of these last suggestions.

ONGOING INVESTIGATION

Comparisons between the Edwards structure map and map patterns of Edwards limestones are only the initial steps of a larger investigation of the controls on Hill Country geomorphic evolution. For example, speculations concerning the effects of proposed fracture sets on erosion patterns suggest that someone go to the field to identify similar fractures in the remaining rock, or look for evidence of dissolution phenomena in rocks below the Edwards. The most up to date geophysical surveys and reports of relavant geologic investigations must be acquired. Finally, mapping still larger areas and making more comparisons is also essential because, just as Selah is nestled in a small nook between fingers of Edwards limestone, the study area reconnoitered here is but part of an arm. Ultimately, the whole body must be understood to fully appreciate the spaces between the fingers.

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Trinity Aquifer System of the Texas Hill Country

John B. Ashworth

HISTORICAL OVERVIEW

In the early 1800s, European immigrants to the Hill Country region of central Texas laid claim to parcels of land with the intent of making a new life by whatever means they could from the rocky terrain (fig. 1). The one ingredient necessary for survival in this harsh land was water. Most homesteads were located near spring-fed streams where water was available for irrigating gardens, watering livestock, powering grist mills, and everyday household needs. This water supply was often supplemented by rain collected from rooftops and stored in cisterns. Most years this water supply was adequate for the minimal demands required by these early settlers. However, during extended periods when rains failed to materialize, most springs weakened and eventually ceased to flow.

Dry spells which probably occurred much too often caused the resourceful new Texans to seek water elsewhere, underground. Rudimentary wells, hand-dug to depths of less than 50 feet, usually encountered enough "seep" water to get through the dry spells. Years later, cable-tool drilling rigs penetrated deeper into the subsurface but usually stopped at depths averaging 100 to 200 feet when the first dependable water-bearing strata was encountered. By the late 1800s numerous deep wells had been drilled in Central Texas bringing artesian water flowing to the surface. One such well was drilled on the State Capitol grounds in 1890. At over 1500 feet in depth, this well penetrated through the Edwards and into the Trinity aquifer. This well continued to flow until 1976 when the well was temporarily plugged.

Rotary driven rigs, capable of more efficiently drilling deeper and wider holes, became increasingly prevalent following World War II. This new drilling technology made the deeper water-bearing zones more accessible for not only municipal supply use but also for the individual homeowner. Wells producing from a combination of lower Glen Rose, Hensell, and Cow Creek provided adequate supplies, even during drought conditions. Rotary driven rigs using a mud circulation system also allowed for wells to be drilled through the Hammett Shale and to the base of the Hosston.

Thus, for many years water supplies in the sparsely populated Hill Country were relatively adequate although not necessarily abundant. Even during the severe drought of the 1950s, the region was able to survive mostly because local citizens had adapted over time to getting along with modest supplies of water. Today an even worse situation than drought looms on the horizon. Urban sprawl is rapidly spreading across the hills creating a density of wells that threatens to deplete the Trinity aquifer.

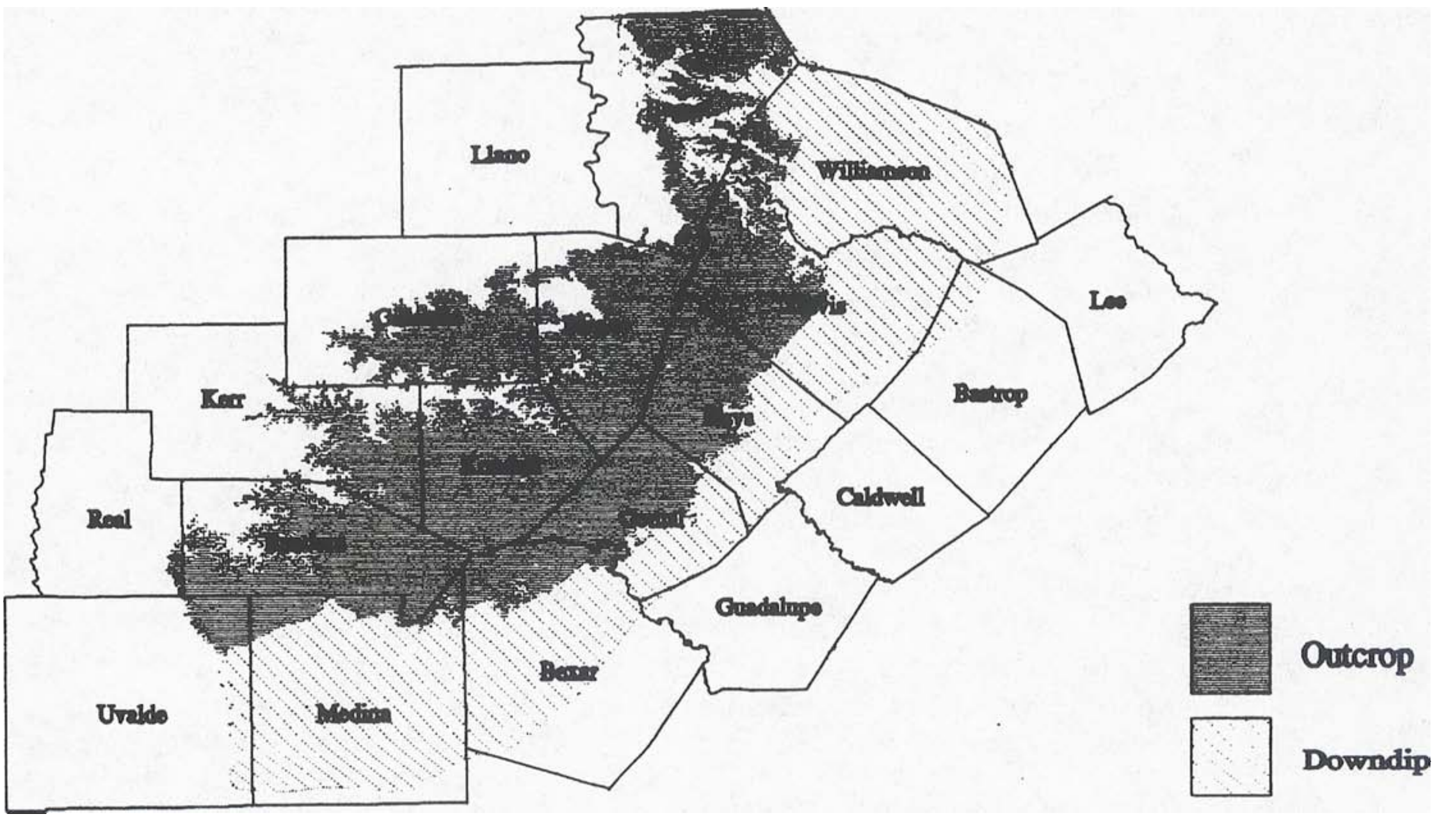

Figure 1. Surface and downdip extent of Trinity Group deposits in the Hill Country area.

HYDROGEOLOGIC SETTING

Lower Cretaceous Trinity Group sediments form a wedge-like, overlapping, transgressive-regressive cyclic sequence that thickens downdip and pinches out against the slope of the Llano uplift (fig. 2). The Trinity aquifer system is comprised of water-bearing formations of the Trinity Group which include in ascending order the Hosston-Sligo, Cow Creek, and Hensell members of the Travis Peak Formation, and the Glen Rose Formation. The Hammett Shale forms an aquiclude between the Hosston-Sligo and the overlying Cow Creek.

Hosston-Sligo Aquifer

Overlying rocks of Paleozoic age, the Hosston Member of the Travis Peak Formation is the oldest Cretaceous unit. Updip the Hosston consists predominantly of terrigenous clastics deposited by aggrading streams draining off the Llano uplands. Downdip the unit becomes increasingly more dolomitic and shaley. Thin conglomeratic zones near the base persist through the downdip limit of the Hill Country region, especially where the Hosston was initially deposited along existing drainage ways. Locally, water well drillers often refer to the Hosston as the "lower Trinity sand". The Sligo Member exists downdip where the Hosston grades upward into a sandy, dolomitic limestone.

Water in the Hosston occurs most prolifically in Kerr and Bandera counties where the aquifer provides a significant amount of the municipal water supply for the cities of Bandera and Kerrville. The Upper Guadalupe River Authority has recently completed a project in which treated surface water is injected into the Hosston for temporary storage and later recovered during peak water demand periods. Downdip, water in the Hosston deteriorates in quality and is contained primarily in the basal conglomeratic zones.

The Hosston and Sligo are overlain by the Hammett Shale, also referred to as the Pine Island Shale, which forms an aquiclude to the underlying aquifer. The Hammett consists of a heaving shale that caves in a newly drilled well and must be cased off if further depth is desired. Because of its depth and the difficulty of drilling through the Hammett, the Hosston aquifer is not commonly used outside of the Bandera and Kerrville areas.

Cow Creek Aquifer

Overlying the Hammett Shale, the Cow Creek Limestone represents a seaward progradation of the shoreline from the southern and eastern flank of the Llano uplift. The Cow Creek is a fossiliferous, white to grey, shaley to dolomitic limestone composed of a fine to medium grained calcarenite with local thinly-bedded layers of sand, shale, and occasional lignite. It forms steep overhanging bluffs and cliffs where it crops out along the eastern extent of the Pedernales, Blanco, and Guadalupe Rivers. The limestone is often honeycombed in the outcrop. The Cow Creek attains a maximum thickness of approximately 90 feet downdip, although 50 to 60 feet is average over most of the area.

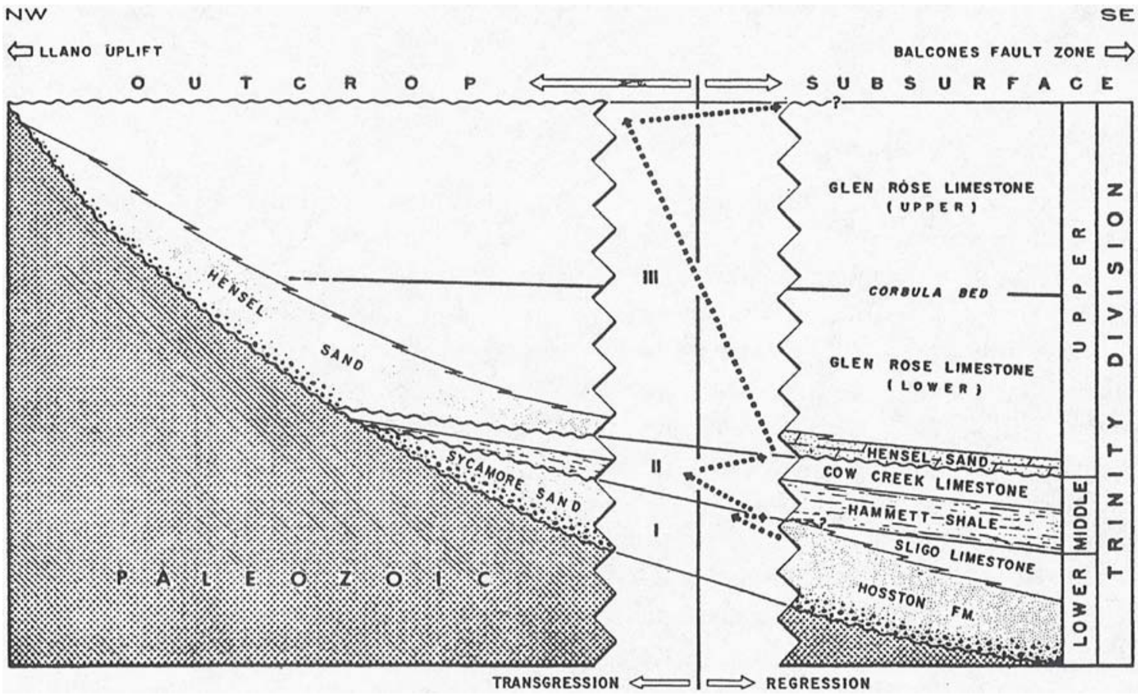

Figure 2. Depositional sequence of the Trinity Group (after Stricklin, Smith, and Lozo, 1971).

Throughout much of the Hill Country, the Cow Creek typically yields 10 to 30 gallons per minute (gal/min) of fresh water to wells. Hydraulic conductivity is particularly well developed in southern Kendall County where some wells produce upwards of 100 gallons per minute.

Hensell Aquifer

The Hensell consists of both continental and marine deposits. Updip in the outcrop along the Pedernales River valley, the Hensell was deposited as coalescing alluvial fans resting on highly faulted pre-Cretaceous rocks. Thick continental deposits of red clay, silt, sand, and conglomerate grade upward into gray limestone of the lower Glen Rose. Farther downdip, the Hensell grades laterally into marine deposits of silty dolomite and shaley limestone of the Bexar Shale. Maximum thickness of 300 feet occurs in Gillespie County and generally thins to less than 100 feet by interfingering into the Glen Rose in a downdip direction. The Hensell Sand is often referred to locally as the "first Trinity" or "upper Trinity" sand.

The Hensell aquifer typically yields less than 50 gal/min of variable quality water to wells in its northern updip extent. Hensell ground water, especially in Blanco and Gillespie counties, may contain elevated levels of sulfate and chloride, and, in some areas, iron. The Bexar Shale typically does not produce water.

Glen Rose Aquifer

The Glen Rose Limestone is the uppermost formation of the Trinity Group and is exposed over approximately three-fourths of the Hill Country. The Glen Rose, along with the Hensell, represents a wedge of sediments deposited in a transgressing sea and is informally separated into upper and lower members. The boundary between the two members is identified by a thin limestone bed containing numerous fossils of *Corbula martinae* that persists throughout the region.

The lower member of the Glen Rose Limestone consists of a massive, fossiliferous limestone at the base grading upward into thin beds of limestone, dolomite, marl, and shale. The top 15 to 20 feet of the lower member, designated the *Salenia texana* zone, is a highly fossiliferous, nodular marl and limestone which is capped by the "Corbula bed." Rudist and coral reefs are characteristic of the basal massive section. Some of the reefs show a high degree of moldic porosity, however, unless the zone has become fractured, the permeability remains low. The lower member has a maximum thickness of approximately 320 feet in the southern part of the region and thins updip by grading laterally into the underlying Hensell Sand.

Because the lower member of the Glen Rose is massive, it is more susceptible than the upper member to the development of secondary porosity which results from joint fracturing and the dissolving action of ground water, and hence is generally the more prolific water-producing zone. Water in the lower member of the Glen Rose Limestone is normally of very good quality although hard. Spring water from the lower Glen Rose is of excellent quality with dissolved solids often under 250 mg/l. The lower member is hydrologically connected to the underlying Hensell Sand.

The upper member of the Glen Rose Limestone consists of laterally continuous, alternating resistant and nonresistant beds of blue shale, nodular marl, and impure, fossiliferous limestone. The uneven resistance to erosion by the alternating beds results in the characteristic "stairstep" topography. The upper member thins updip from a maximum thickness of approximately 450 feet. In the northern part of the region where the lower member has pinched out, the upper member thins rapidly by grading laterally into the Hensell Sand. The Glen Rose Limestone pinches out north of the Pedernales River.

Two evaporite zones occur within the upper member. The first zone occurs at the base of the member, and because of its high resistivity curve on electric logs, it serves as a convenient correlation marker between the upper and lower members. The second evaporite zone is located near the middle of the member and has the same characteristics. On the outcrop and within the zone above the water table, the evaporite has often been leached, resulting in slumping and distortion of overlying rocks.

Wells developed in the upper Glen Rose generally produce water of poor quality. Low permeability of the upper member restricts water movement which causes an increase in mineral concentration. Slow movement and long contact of ground water with highly soluble evaporite zones results in excessive sulfate content. Unless water of good quality is encountered, it is highly recommended that the upper Glen Rose be cased and cemented in wells to prevent its commingling with fresher water at deeper depths.

REGIONAL HYDROLOGY

Recharge

Recharge to the various aquifer zones is not completely understood, however, certain aspects are apparent. Most recharge is derived from local precipitation that infiltrates downward through cracks and crevices in the exposed bedrock. This is most apparent along Cibolo Creek where, except during flooding conditions, all water is diverted underground. Although the Trinity is predominantly limestone, extensive mega-karst permeability has not developed to the extent observed in the adjacent Edwards aquifer. Although infiltration is most prevalent within streambeds, the steepness of the hills results in rapid runoff with very limited residence time for infiltration. Recharge to at least the Glen Rose is relatively fast as is observed by the rapid water-level rise in wells following precipitation events. In some cases, this rapid response is also seen as deep as the Cow Creek zone. Direct vertical conduits to the basal Hosston and Sligo are not as apparent.

Limited recharge occurs along the major rivers that traverse the Hill Country. Stream gauge evaluations indicate that these rivers show a base flow gain throughout much of this region until reaching the Edwards outcrop at the Balcones Fault Zone.

Another component of recharge that has not been fully studied is the probable lateral flow from the Edwards Plateau into the westerly part of the Hill Country. Regional water-level contours indicate that ground-water movement on the Plateau is toward this area.

Movement

Regionally, ground water contained in all the Trinity water-bearing zones moves in a downdip direction, basically perpendicular to the Balcones Fault Zone trend. Average gradient of the potentiometric surface is approximately 20 to 25 feet per mile. Locally, there appears to be a component of movement away from the major topographic river divides and toward the river valleys. Horizontal flow preference within the Glen Rose limestone hills results in much of the shallow infiltrating ground water migrating laterally along the top of marl beds and eventually seeping from the sides of the hills. These springs and seeps contribute to the base flow of the rivers. An average annual increase in base flow of 31,000 acre-feet has been measured on the Guadalupe River between the Comfort and Spring Branch gauging stations.

Water Level

Water levels in wells completed in the Trinity tend to show significant response to seasonal conditions and to low storage capacity. Levels decline rapidly during hot, dry summer months and react rapidly to recharge from increased precipitation in the fall, winter, and spring months. This condition is exemplified by the "sawtooth" pattern on the hydrograph shown in figure 3. Also apparent on the hydrograph are the effects incurred by the short droughts of 1989 and 1996. Prior to significant rainfall in August of 1996, a large number of wells completed in only the Glen Rose went dry. Long-term water-level declines have occurred in some areas as a result of numerous wells being drilled in a limited area, thus causing overdevelopment of the local aquifer.

Chemical Quality

The chemical quality of Trinity ground water is a function of residence time and mineralogy of the host rock. Rapid recharge and higher hydraulic conductivity result in lower Glen Rose and Cow Creek water containing the least amount of dissolved solids. Although the upper Glen Rose and Hensell may recharge rapidly, their mineralogical makeup often results in elevated levels of specific dissolved constituents. Especially troublesome are sulfates leached from evaporite zones in the upper Glen Rose. Except in Bandera and Kerr counties, the water quality of the Hosston is marginal at best.

Ground-water quality in all the Trinity aquifers degrades in a downdip direction and usually becomes unusable for most uses by the time it reaches the vicinity of the Balcones Fault Zone. An exception to this occurs in Williamson County where Trinity water is of acceptable quality as far east as the City of Taylor.

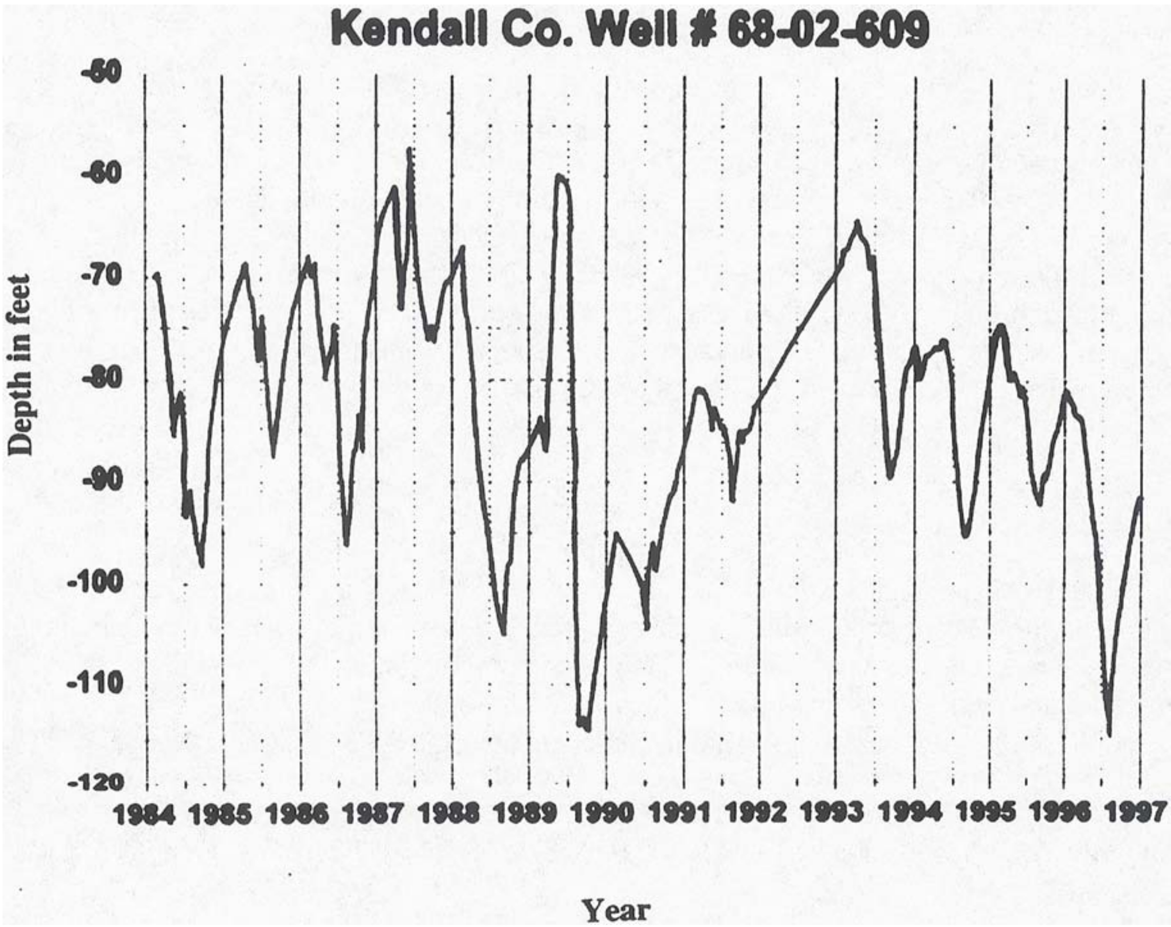

Figure 3. Water-level hydrograph of a Cow Creek aquifer well in Kendall County showing seasonal and long-term trends.

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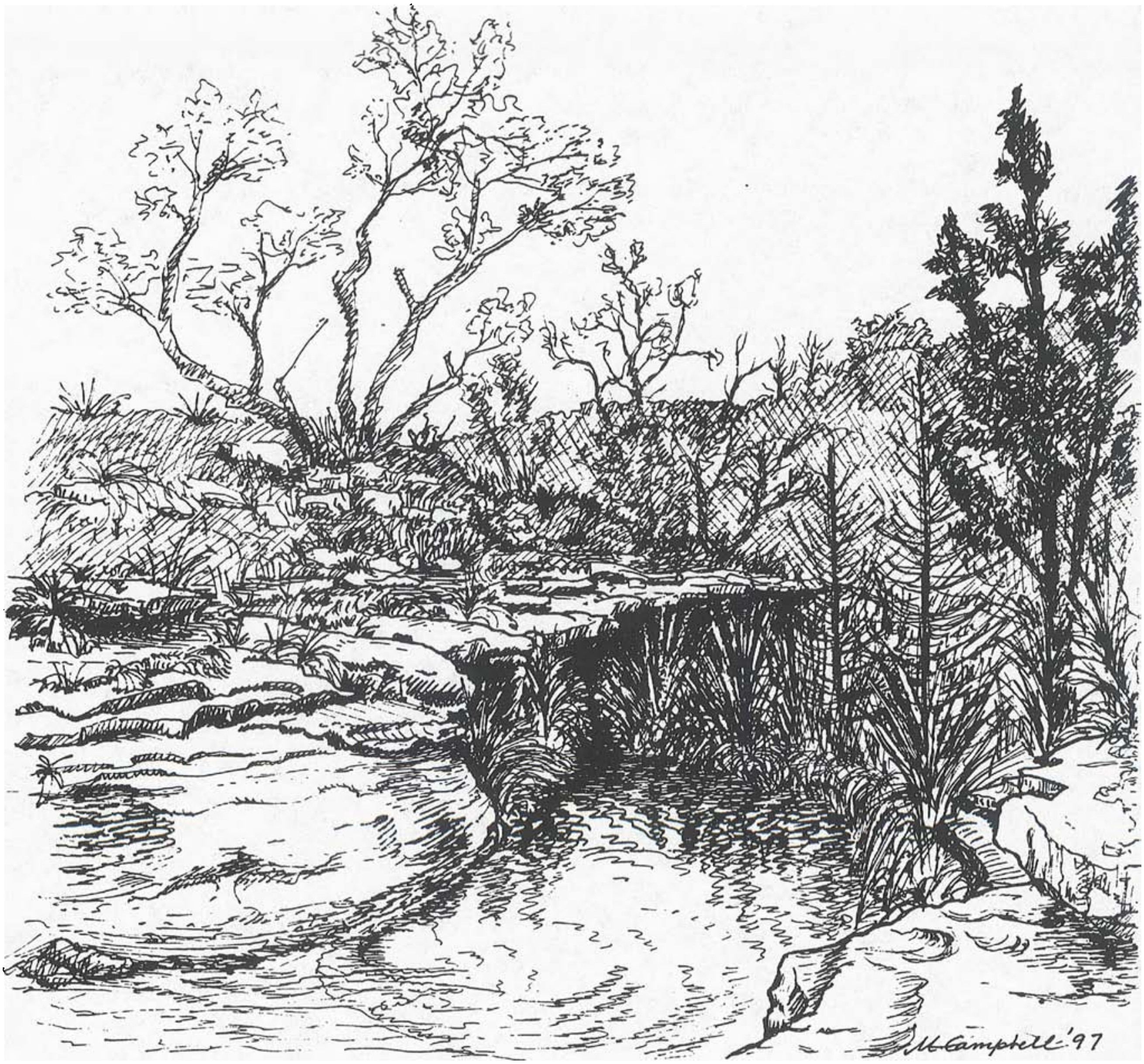
M Campbell '97

A Reappraisal of the Brackett Soil Series

L.P. Wilding

INTRODUCTION

In the Hill Country of Central Texas, strongly calcareous, loamy skeletal, soils are derived from Cretaceous-age, interbedded dolostone/limestone strata of the Glen Rose Formation. Well drained upland soils in these gently undulating to steeply rolling landscapes are highly variable, stony and fragile systems that are easily subject to degradation if mismanaged. One of the major soils mapped on stepped terrains of upland summits and valley slopes is the Brackett series. This benchmark series was first recognized and established in Kinney County in 1911, during the Reconnaissance Soil Survey of Southwest Texas. The series was used in the 1915 Soil Survey of Bell County, Texas, and its type location remained there for 40 years. Hence, the Brackett series was one of the first soils to be recognized and mapped in early soil surveys of the Texas Hill Country; it has existed as an established series unit for more than 70 years.

To date, the series has been mapped and correlated in 23 survey areas including 27 Texas counties and occupies over 1.7 million acres (Fig. 1). Mean annual precipitation over this area ranges from 685 to 940 mm (24 to 27 inches). The soils have been mapped and correlated over a wide range of bedrock types including shaly clays, clalks, limestones, and marls that are weakly to strongly interbedded depending upon geology. It is clear that the Brackett series was a very extensive soil series associated with limy bedrocks of the Central Texas Hill Country. It encompassed an extremely broad range of geographic, geologic, climatic, topographic, and soil conditions. Land use of this limestone region traditionally had been rangeland, owing to the widespread stony (non-arable) soils and rugged slopes. In recent years, however land-use patterns have changed. The Hill Country is highly prized as sites for residential and industrial developement in urban-fringe areas of metropolitan centers such as Austin and San Antonio. Likewise, it is used for recreation and hunting in more rural sectors. Among issues of environmental concern are the ability of these soils to buffer soil and groundwater pollution, to serve as a filter for waste water application, and to mitigate against increased surface runoff and erosion in areas of increased impervious cover. Hence, with the change in land use from extensive rangelands to intensive suburban development, there is much greater impetus for reappraisal of the Brackett series.

EARLY CONCEPTS OF BRACKETT SERIES

Early concepts of the Brackett series characterized these soils as thin and strongly calcareous with low infilitration rates, low water retention, high surface runoff, minimal bioremediation, and slight pedogenic development (Werchan et al, 1974). In fact, many lay

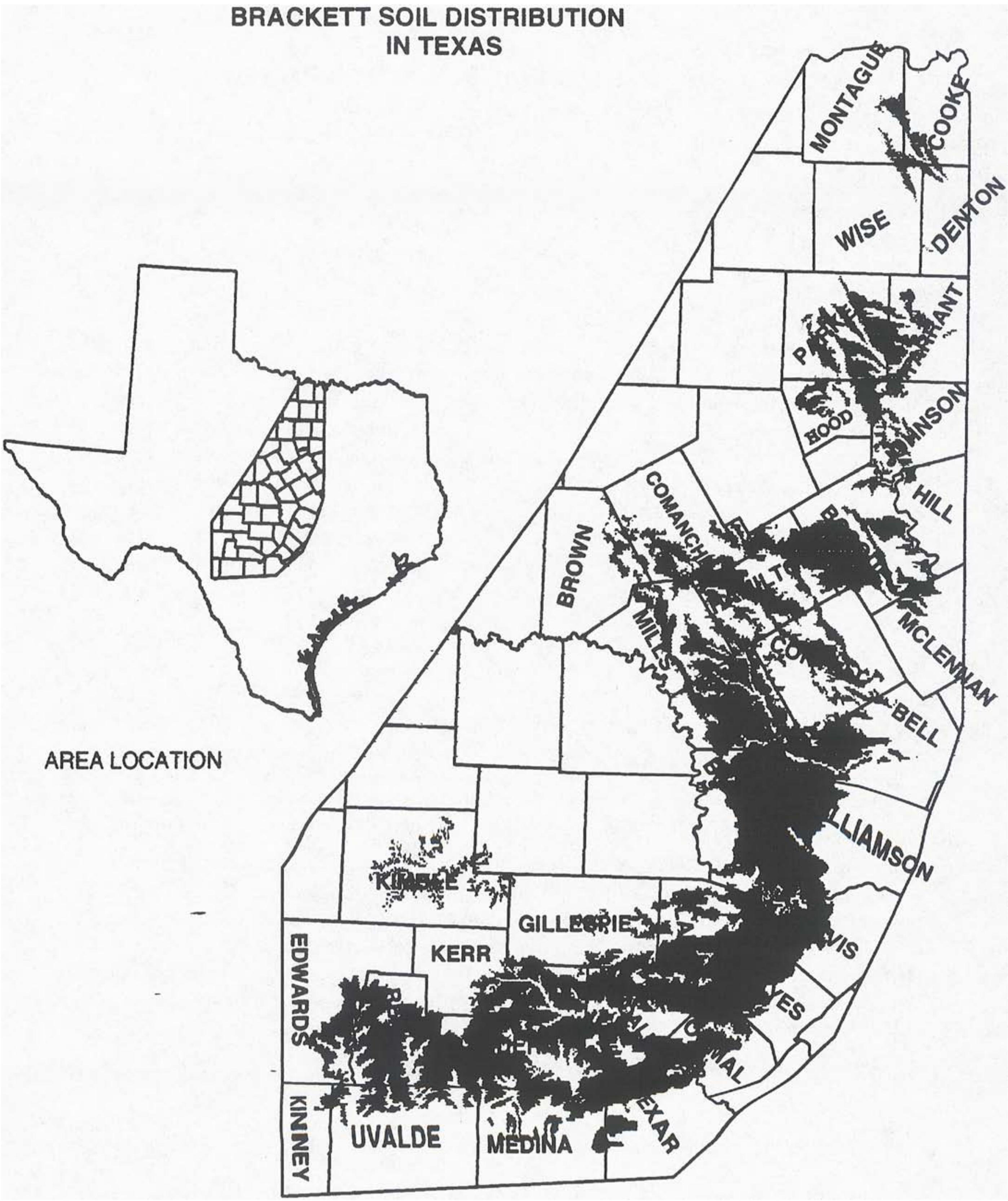

Figure 1. Location of Brackett series map units correlated in soil surveys of the Central Texas Hill Country (courtesy of Mr. Dennis Williamson, USDA - Natural Resources Conservation Service, Temple, Texas, 1997)

public and even some geoscience professionals questioned whether "soils" existed in these landscapes or whether the land surface simply represented a geologic regolith without the classical biological activity attributed to soils. This misnomer was propagated in Travis County Soil Survey Report with the concept that the Brackett series consisted of "...shallow, well drained soils...underlain by interbedded limestone and marl" (Werchan et al, 1974). Permeability was estimated to be moderately slow (0.20-0.63 inches/hour). Organic matter was considered low and pedegenic development minimal to non-existent.

Concepts of the Brackett soils were incompletely understood in earlier soil surveys of the Hill Country both by soil science professionals and the lay public because the standard field equipment for observing soils at depth was an auger and spade. These tools were not well adapted to the interbedded hard and soft limestone bedrock of the Hill Country. Frequently exposures of soil conditions were shallow, incomplete and limited by the very stony, rocky nature of the soils. Secondly, the location where many soil observations were made on these stepped landform terrains was on the tread positions of the steps. The working hypothesis was that observations would be made where the soil was predicted to be deepest because these landforms were judged to be the most geomorphically stable. In retrospect we now know the deepest soils are coincident with the steeper portions of the steps, the risers. Lastly, the intensity of land use dictates the scale of soil surveys and consequently the depth and frequency of observations made. In the Hill Country, where Brackett soils were mapped, the land use was extensive, the purpose was for farm and ranch planning. Sophisticated soil observations (such as backhoe trenches) were not made nor deemed necessary because only the general nature of soil properties and patterns were considered germane to the objectives of the soil survey. The precise character of the soils, their hydrology, depth limits, pedogenic processes, biological activity, urban interpretations, and environmental sensitivity were not comprehensively determined or evaluated.

With adoption of a new soil classification system (Soil Taxonomy, Soil Survey Staff, 1975), accompanied by more intense land use pressures and multiple applications of the soil survey, the concept of the Brackett series was brought into question. It became apparent that its range of soil attributes (depths, textures parent materials etc.), geographical extent, and occurrence of its climatic provenance should be restricted. Detailed observations that permitted more precise statements about use, management and behavior of the Brackett series were needed. Other similar soils, but with significant differences, were recognized and established in areas once mapped as the Brackett series (Girdner and Lane, 1982). This led to progressive reevaluation of the concept of the Brackett soils from the early 1980's to present.

EVOLVING CONCEPTS OF BRACKETT SERIES

Work by Girdner and Lane (1982), Rabenhorst et al. (1984, 1991), Rabenhorst and Wilding (1986 a,b,c), and West et al. (1986, 1988, 1989 a,b) shed new light on the Brackett and similar soils. They found these soil to be bedrock controlled, deeper than previously believed, unusually high in organic carbon contents (relative to their light colors), and with greater leaching and translocation of carbonates than commonly invoked. More recent trench studies by

Wilding (1992 a,b), Woodruff, et al. (1992), Wilding and Woodruff (1993, 1994) and Marsh and Marsh (1994, 1995) have demonstrated that the only effective way to investigate these soils is with backhoe exposures that traverse the riser and tread microelements of the step perpendicularly. Through such investigations, it has become evident that Brackett soils, previously mapped as shallow units, exhibit greater depths, spatial diversity, subsoil development, biological activity, root development and localized high-infiltrating surface zones than previously envisioned. This is especially true on more steeply sloping riser positions. Currently the official series is recognized as very deep soils formed in soft marly and limestone bedrocks without the hard ledge-former strata (USDA - Soil Conservation Service, 1989). While this change in series concept appropriately recongnizes the Brackett series as a deeper soil than earlier concepts, it does not adequately account for the spatial diversity of this soil with shallower counterparts on stepped-landscape terrains, as observed in more recent studies. Further, the present concept still considers these soils as Inceptisols rather than Mollisols.

SOIL-LANDFORM PATTERNS

Comprehensive data sets obtained from my recent research on Brackett soil-landform patterns have been presented elsewhere (Wilding, 1992a; Wilding, et al., 1997), and only general trends and relationships will be presented here. To date a total of 54 trenches have been studied in map units of Brackett series. Cross-sectional profiles, with elevation control, have been described at over 250 locations within these trenches, and from these locations selected physical, chemical, biological and mineralogical laboratory data have been obtained at 65 sites considered representative of the soil conditions expressed. Also, infiltration rates, surface runoff, soil moisture status (including temporal water tables) and precipitation data have been collected to document the hydrological nature of the Brackett and similar soils in the stepped terrains.

The Hill Country stepped terrain is underlain by Cretaceous limestone and dolostone units of the Glen Rose Formation (Woodruff et al., 1992.) Hard dolostone (or crystalline limestone) beds alternate with softer marly beds which upon weathering evolve into "stair-step hills" composed of "treads" and "risers" (Fig. 2). The variable geometry of the steps is dependent upon the thickness of alternating hard and soft beds within the geologic strata. The greater the proportion of soft beds, the greater the soil thickness on risers and commonly the greater expression of benched landforms. The hard beds stand out as ledges above risers and form resistant substrate underlying treads.

Figure 3 schematically illustrates the general soil landform relationships from riser to tread elements within the stepped terrain. Decreasing soil thickness, biological activity, soil permeability, water storage, and vegetative cover occur in tranversing from risers to treads. Increased surface runoff, sediment transport, soil hydrological groups, and hydrological curve numbers also occur from risers to treads. The repeating riser and tread microforms of these steps have important pedological, hydrological and biological impacts on the functioning of these complex soil units. In the moderately to strongly-stepped terrain, the soils are controlled by riser and tread repeating microtopographic units in which the steps are 1-4 m high and 10-20 m long. The thickest and best developed soils are classified Udic Calciustolls, or occasionally as Petrocalcic Calciustolls (Soil Survey Staff, 1975) and range in thickness from 1-3 m. They are

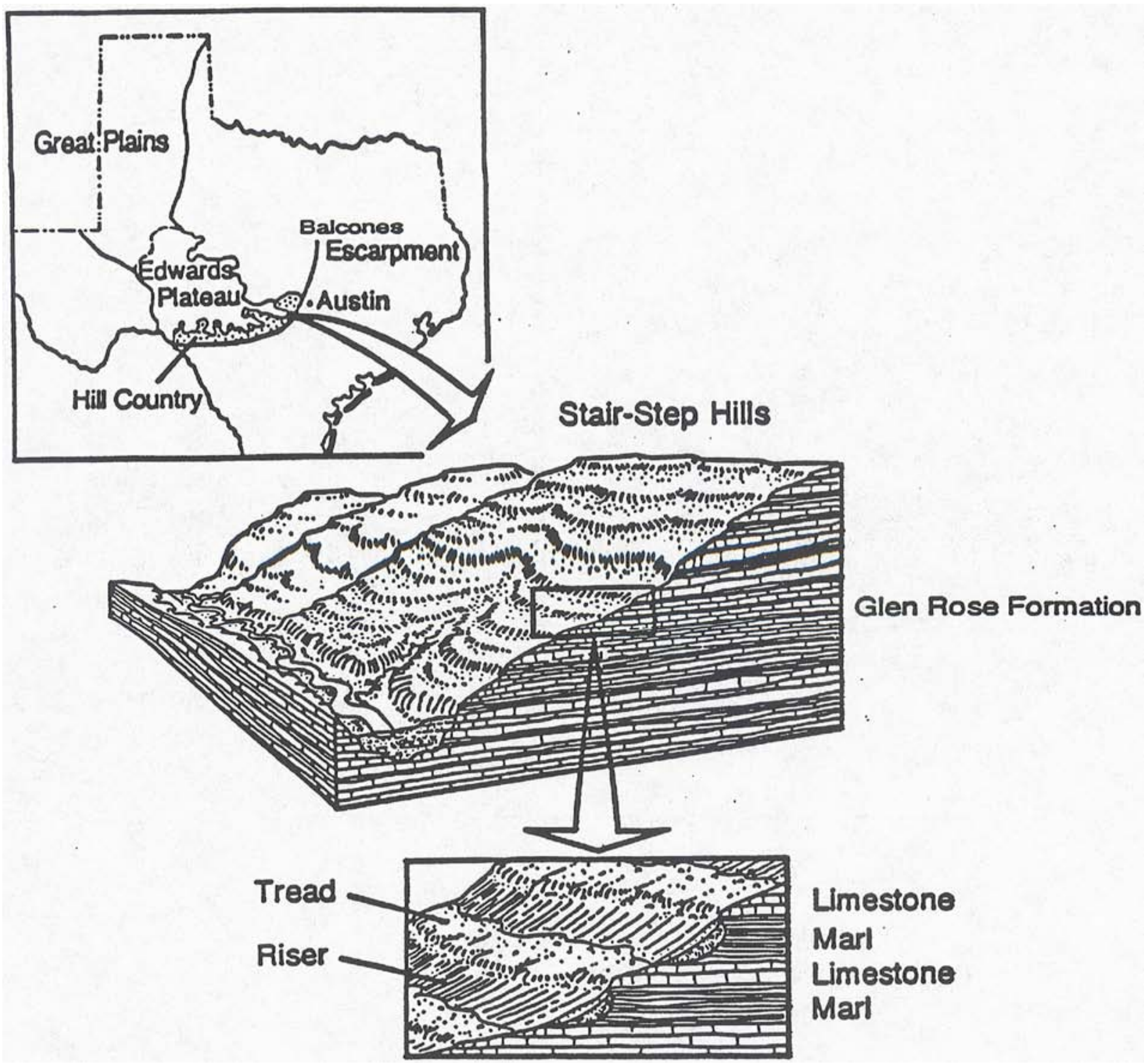

Figure 2. Microtopographic elements of Central Texas Hill Country, in context with stepped terrain, and regional physiographic and geological features. (Woodruff, 1992. Graphics courtesy of Nina Marsh, Terra Syn, Inc., Flint, MI).

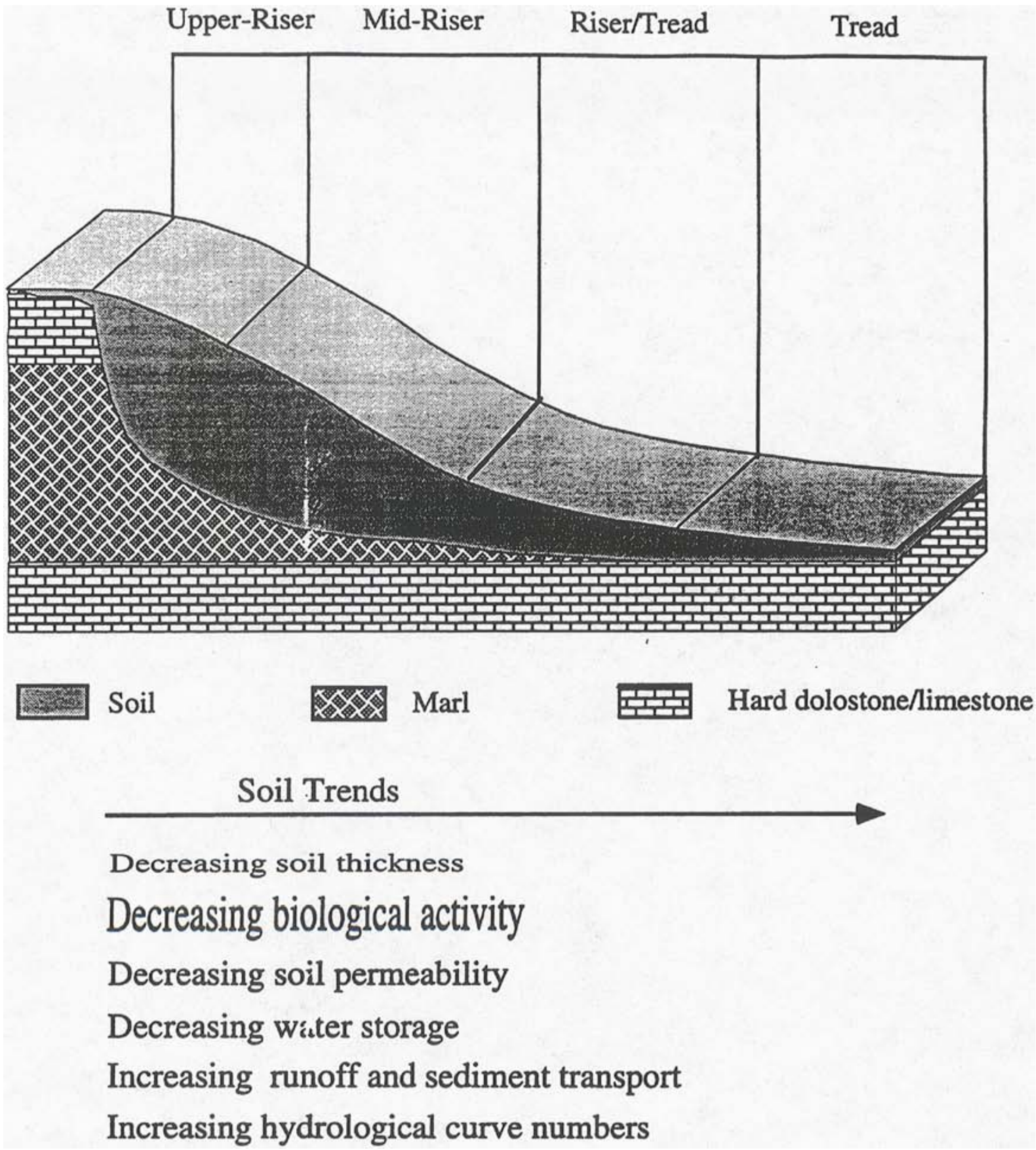

Figure 3. Soil property trends as a function of stepped microtopography.

set as disjunct wedges along steep-gradient risers. Soils on risers are developed in a thin veneer of limestone/dolostone-rubble colluvium which serves as the parent material for organic-matter rich, gravelly A horizons. These are uncomformably superposed over partially weathered in-situ marls in which pedogenically-enriched carbonate horizons (calcic or petrocalcic) are formed. Calcic horizons with pedogenic carbonate forms occur as soft masses within the matrix, as pendants on lower surfaces of carbonate clasts, calcite cements, joint infillings, calcite nodules and concretions. Petrocalcic horizons occur as laminar caps on hard, weakly-jointed ledge former strata, as laminar caps above indurated and plugged carbonate layers, and as cemented, indurated dolostone/limestone clasts. The formation of calcic versus petrocalcic horizons in these landforms is controlled by local hydrological environments within steps which function essentially as independent hydrological units. Risers serve as local recharge within stepped terrains while the treads are the discharge areas. Distributions of calcic and petrocalcic horizons reflect these phenomena. Both calcic and petrocalcic horizons increase in expression downslope from risers towards concave riser/tread or tread microtopographic positions (Wilding et al,. 1992a). Commonly the greatest leaching occurs in the risers with subsequent translocation vertically and laterally towards the tread.

On nearly level to gently sloping treads, soils are thinner (< 0.5m) and classified as Lithic Ustochrepts, Lithic Calciustolls, and Lithic Petrocalcic Calciustolls (Soil Survey Staff, 1975). This means that in these soils the hard ledge-former starta are within 50 cm of the soil surface, the soils are lighter colored, and the soils contain less organic matter.The sola are formed in thin, loamy gravelly, carbonatic, pedisediments derived as erosional products from upslope transport. These sediments are admixed with weathered marls or superposed directly over the hard bedrock in which many of the joint planes are partially plugged with pedogentic calcite cement. Surfaces of the soils are commonly crusted and this favors runoff and erosion of sediments to the next downslope riser.

In less steeply sloping, weakly-stepped terrains, the soil patterns are similar to those described above, but the treads compose a much larger proportion of the step geometry. Here, the soils are moderately deep or shallow and have more strongly expressed calcic and petrocalcic horizons overlying the weakly-jointed ledge-former dolostone/limestone strata. These strata are more strongly plugged with pedogenic calcite-cement than on more strongly-stepped terrains. Soils in weakly stepped landforms are commonly Petrocalcic Calciustolls or Lithic Calciustolls on risers, and Lithic Petrocalcic Calciustolls or Lithic Ustrochrepts on treads. In soils derived from dolomitic-rich beds, most of the soil textures are gravelly or very gravelly silt loam. This reflects the higher silt content of dolomite residua with euhedral dolomite rhombs as the silt separates.

HYDROLOGICAL PROCESSES

Hydrological processes in these stepped landforms are similar to those proposed by Marsh and Marsh (1994). Variations in bedrock present multiple barriers to ground water flow so that infiltration enters a series of disjunct perched water tables that fill and drain according to prevailing weather conditions. This results in water moving in a relatively slow cascading, downslope fashion from one step to the next via infiltration, throughflow, lateral discharge (above ledge-former strata), recharge (through ledge-former strata), and surface runoff. Important hydrological implications of this model are long mean residence times, little fissure/fracture flow through ledge-former strata, multiple cycles of water storage and bioremediation, retention of eroded sediments, and high evaportranspiration consumptive use. These hydrological processes have remarkable impact, not only on pedogenesis, but upon land use, location of protective biophysical buffers, and potential use of risers for on-site waste-water treatment strategies (Marsh and Hill-Rowley, 1989; Woodruff and Longly, 1979; Marsh and Marsh, 1996; Wilding and Woodruff 1993, 1994).

SUMMARY

In summary, the Brackett series was not found to be a single soil but a complex assemblage of deep, moderately-deep, shallow and very-shallow soils linked together in a systematical pattern as disjunct soil units associated with the stepped landforms. In spite of this increased knowledge base about soils on these stepped terrains, previously mapped as Brackett series, it will not be possible to show the close-interval spatial variability of soil conditions on maps commonly employed in standard soil surveys of this region. Soil scientists may recognize these soil differences on the ground but the scale of mapping simply doesn't allow such detail to be portrayed on the map. Soils corresponding to such microtopographic features will necessarily have to be shown as map units of soil complexes. Several different soils will be included in the complex but the description of the map unit will carefully convey the pattern of different soils relative to the stepped landform, and the proportionality of each. Hence, a representative number of trench observations and corresponding laboratory data for soils contained in the map unit is needed to develop an accurate concept of the Brackett and similiar soils composing the complex unit. Knowledge of this complex unit, with its corresponding hydrological, physical, chemical and biological behavior for multiple land use interpretations, will be a major step forward in reevaluating concepts of the Brackett series in the central Texas Hill Country.

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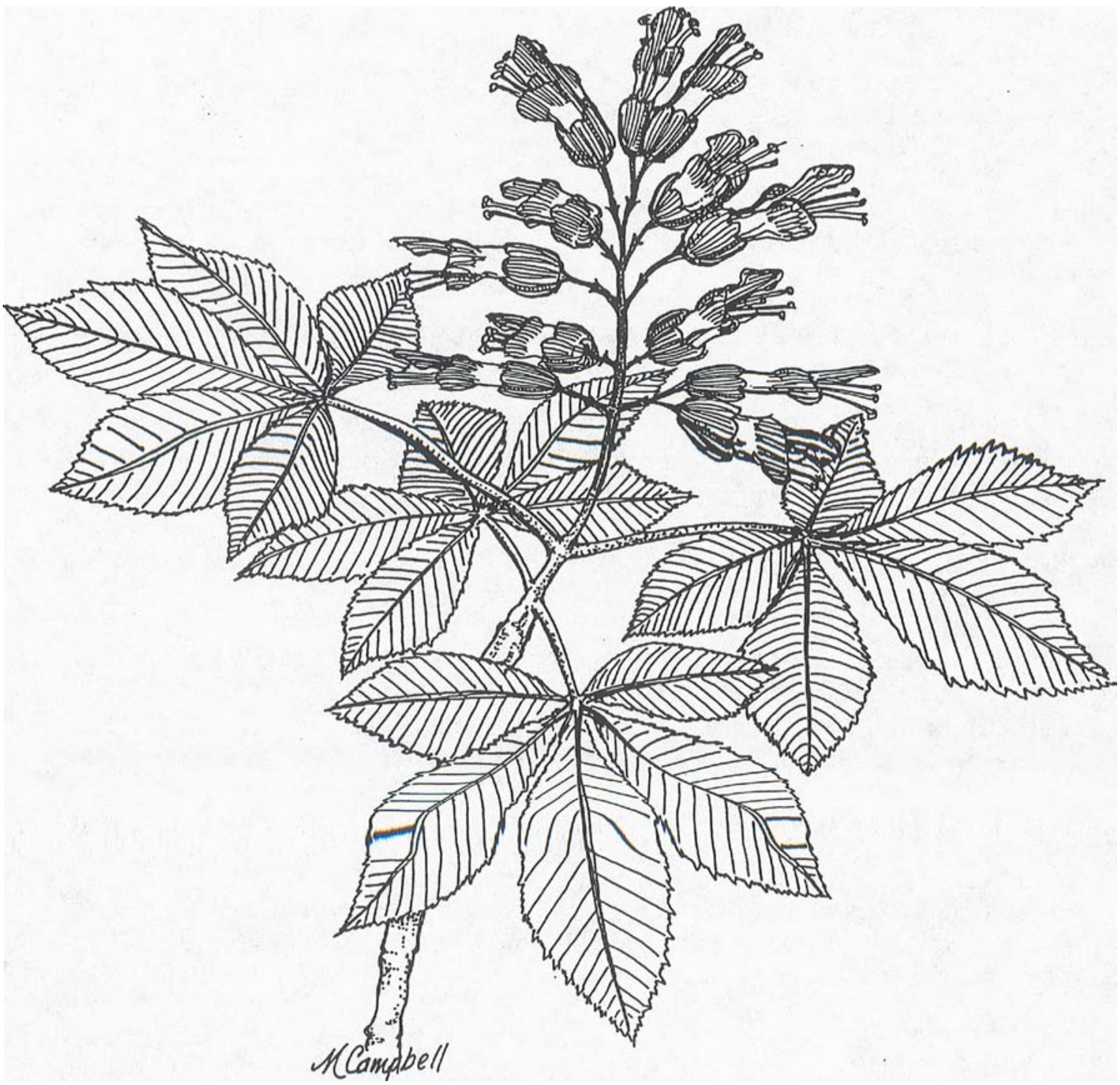


The Grasses and Grassland Character of the Bamberger Ranch

David W. Dunlap

Illustrated by Margaret C. Campbell

INTRODUCTION: THE BIG PICTURE

Why should we concern ourselves with grasses? After all, most of us know about grass...it's the stuff that causes Americans to occupy so many weekend afternoons during the summer pushing the lawn mower. And, to look at it still another way, grass is the collection of wispy things that form the nebulous background in landscape photos. Right? Well, yes. It can be both of those things, but if one takes a broader perspective it becomes clear that grasses contribute far more than simply to a suburban lifestyle and landscape photography.

Grasses unquestionably represent the single-most economically-important of all plant families. The cultivation of grasses formed the foundation of agriculture, which was in turn the foundation of civilization. The following food staples - corn (maize), wheat, rice, barley, oats, sorghum, millet and, of course, the main source of refined sugar, are all grasses (Powell, 1994). Besides the contribution that grasses make to our food supply, they play other key roles, described elsewhere, below.

WHAT ARE GRASSES, ANYWAY?

Grouping plants by family is a convenient way of describing plants having similar evolutionary histories and physical characteristics. According to Gould (1968), of all plant families worldwide, the family of grasses (known as the Poaceae or Gramineae) is the fifth largest, having between 7500 and 10,000 species. It is exceeded in size only by the Asteraceae (e.g., sunflowers and daisies), Orchidaceae (e.g., orchids), Fabaceae (e.g., peas and beans), and Rubiaceae (e.g., coffee and quinine). Of the nearly 5,000 species of flowering plants in Texas, 523 species are grasses.

Typically, grasses have parallel-veined leaves and reduced, somewhat inconspicuous flowers. The flowers are called florets and they are comprised of the male and female reproductive parts (i.e., usually three stamens and one pistil, respectively), as well as rudimentary, fleshy scale-like structures called lodicules enclosed between (generally) two small bracts. The inner bract is called the palea and the outer is called the lemma. Florets may be solitary or grouped together in clusters, called spikelets, with subtending bracts called glumes.

Grasses can have three kinds of stems, or culms, depending upon the species: a typical upright, aboveground stem; an aboveground yet trailing stem or runner (called a stolon); and an underground stem called a rhizome. Stolons and rhizomes are adaptive structures that allow genetic individuals to spread over an ever-larger area, eventually forming large clones. Turf, or sod, may be formed by an ever-thickening mat created by a single individual or many individuals whose stolons and/or rhizomes have intertwined in their attempts to lay claim to available resources.

Some grasses, however, lack stolons and rhizomes. These are called bunch grasses, because of their growth habit. The particular habit of several common grasses found at Selah (Bamberger Ranch) are shown in the species' descriptions below.

ORIGINS AND DISTRIBUTION

Powell (1994) cites Cronquist (1988) and Crepet and Feldman (1991) in stating that there is mega-fossil and fossil pollen evidence of the existence of grasses as early as the Paleocene/Eocene boundary; also indicating an Upper Cretaceous origin for the family, with "major diversification...well underway in the Miocene, more than 25 million years ago." Grasslands now occur worldwide, although somewhat reduced from what may have been as much as one quarter of the land surface.

In North America, grasslands were a predominant landscape feature covering an estimated 700 million acres (Gould, 1968). The most prominent of these grasslands ranged from Canada to Texas and from the Mississippi River to the Rocky Mountains. It was known as the Great American Desert, likely because of its paucity of trees. It was, in fact, three prairies intergrading one into another from east to west: the tallgrass prairie, the midgrass prairie and the shortgrass prairie. Of that once-vast prairie, the remaining relatively undisturbed acreage can be counted in the thousands of acres, rather than hundreds of millions.

Grasslands, however, aren't mere assemblages of different species of grasses. Depending on geography, a variety of forbs (i.e., non-grass, non-woody species), shrubs and trees are components of grassland vegetation. More or less treeless grasslands are commonly known as prairies, as mentioned above; whereas grasslands with scattered individuals or motts (i.e., clumps) of trees are referred to as savannahs.

In Texas, elements of all three prairies of the Great Plains still define several vegetational areas. Of the ten vegetational areas identified by Gould (1962), nine have (or did have) distinct grassland components: the Gulf Prairies and Marshes, Post Oak Savannah, Blackland Prairies, Cross Timbers and Prairies, South Texas Plains, Edwards Plateau (in which the Bamberger Ranch is located), Rolling Plains, High Plains, and the Trans-Pecos Mountains and Basins. Apart from the east Texas Pineywoods, Texas is clearly a land of grasses.

Blanco County lies near the eastern edge of the Edwards Plateau: an area of primarily Lower Cretaceous limestone sediments that have been deeply dissected by the action of stream-cutting and erosion. The overall vegetation of the area is characteristic of the Juniper-Oak-

Mesquite Savannah, but influenced by the fact that it lies near the western edge of the Blackland Prairies (Bureau of Economic Geology, 1977). Another reference (McMahan, et al., 1984) calls these vegetation types Live Oak-Mesquite-Ashe Juniper Parks and Live Oak-Ashe Juniper Woods.

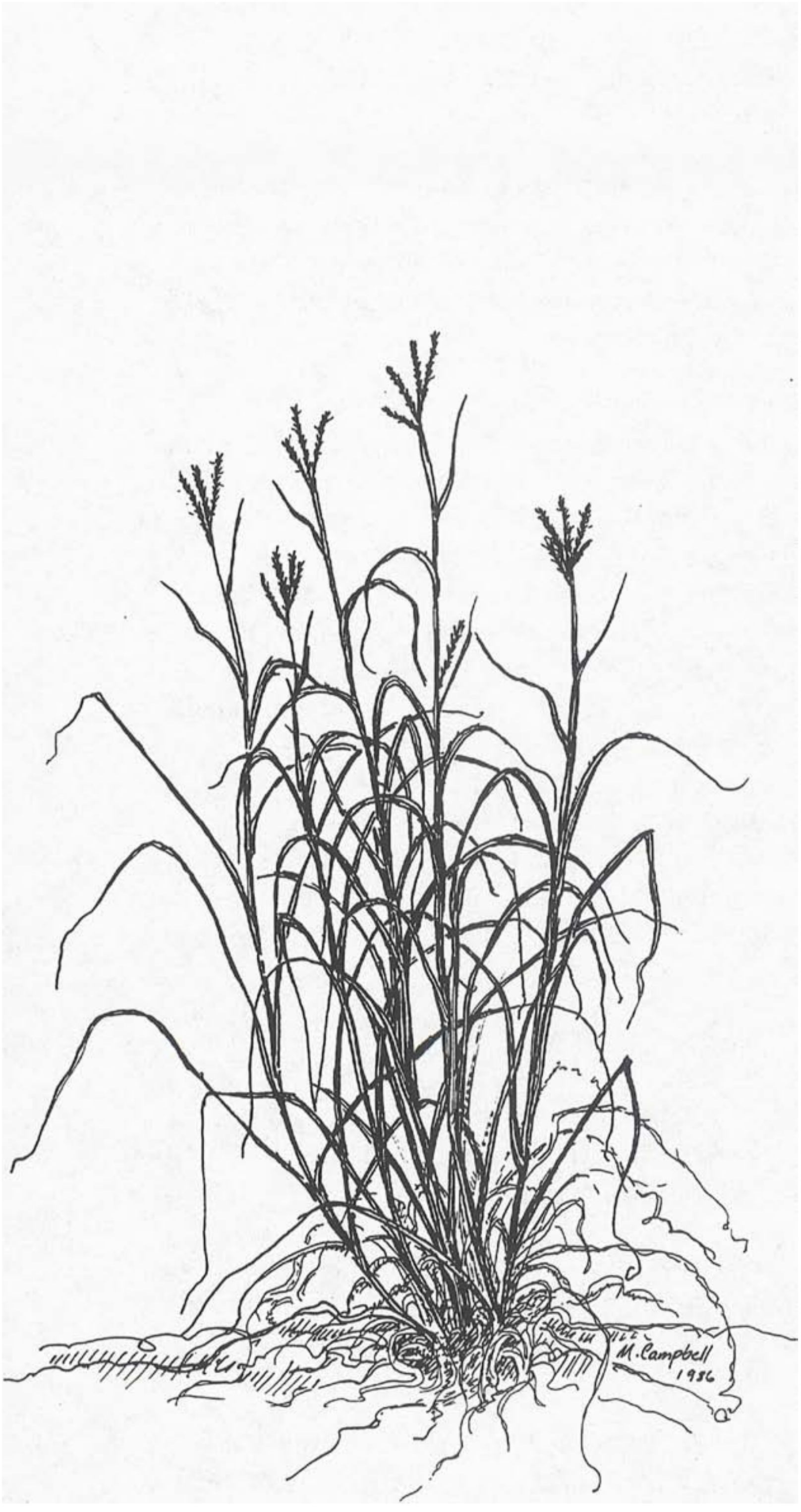
The vegetation of the eastern Edwards Plateau is characterized by an overstory comprised in large part by live oak (*Quercus virginiana*), white shin oak (*Quercus durandii var. breviloba*) and Texas red oak (*Quercus buckleyi*), and dense stands of Ashe juniper (*Juniperus ashei*) known as "brakes." Honey mesquite (*Prosopis glandulosa*) can be found on the deeper-soiled tracts and the sandy terraces of many streams and rivers.

The shrub layer of the vegetation is dominated by agarito (*Mahonia trifoliolata*) and Texas persimmon (*Diospyros texana*), whereas the herbaceous vegetation is primarily a mixture of grasses with mixed heights including little bluestem (*Schizachyrium scoparium*), silver bluestem (*Bothriochloa laguroides ssp. torreyana*), sideoats grama (*Bouteloua curtipendula*), Texas wintergrass (*Stipa leucotricha*) and Texas grama (*Bouteloua rigidiseta*), as well as several species of threeawn grass (*Aristida spp.*). Other associated grasses include tall dropseed (*Sporobolus asper*), buffalograss (*Buchloa dactyloides*), common curlymesquite (*Hilaria belangeri*), tall grama (*Bouteloua pectinata*), slim tridens (*Tridens muticus var. muticus*), and seep muhly (*Muhlenbergia reverchonii*), to name just a few. The herbaceous vegetation includes characteristic species of both the midgrass prairies of the central and eastern plains (e.g., little bluestem and sideoats grama) and the drier shortgrass prairies of the western plains and southwest (e.g., the threeawns and buffalograss). Also, all four of the primary components of the tallgrass prairie: big bluestem (*Andropogon gerardii*), little bluestem, indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) can be found (figs. 1, 2). From place to place these species may vary (as individual species or in association with other species) from locally abundant to entirely absent (Dunlap, 1983).

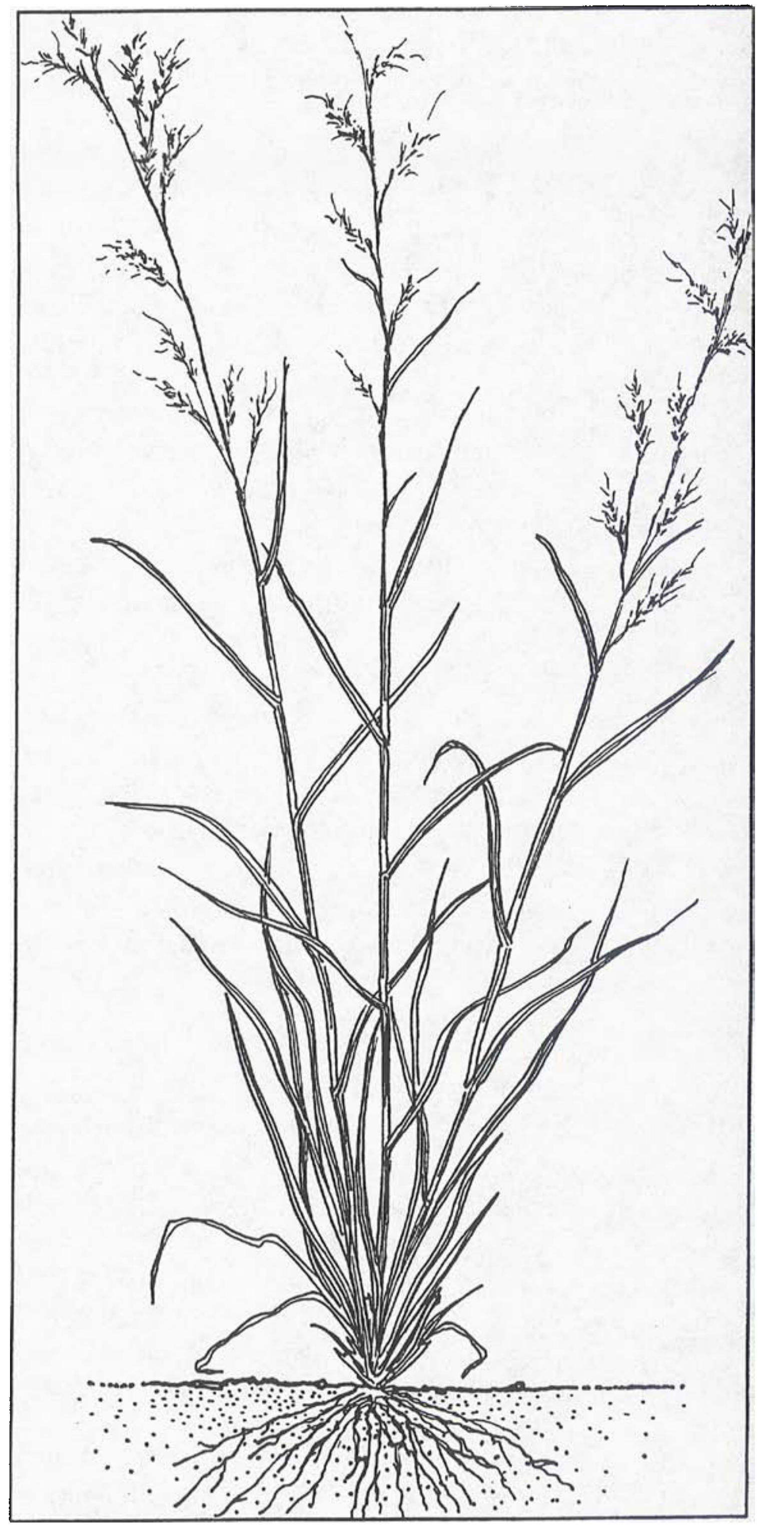
With respect to the distribution of grasses and affiliated species within associations on the eastern Edwards Plateau, studies indicate that there is a definite correlation between the vegetation found on sites and the physical attributes of those sites. In particular, mean soil depth and its negative correlate, percent slope, prove to be the physical parameters most highly correlated with the distribution of species into recognizable associations.

There appears to be an approximate dichotomy of grassland community types in this area: flat sites and slope sites. Flat sites are characterized physically by relatively deep, fine textured soils with lower pH, whereas slope sites are generally shallow, coarse textured soils of higher pH.

Vegetatively, flat sites are typically characterized by a predominance of the following grasses: Texas wintergrass, plains lovegrass (*Eragrostis intermedia*), Texas tridens (*Tridens texanus*), Texas grama, red threeawn (*Aristida purpurea var. longiseta*), Hall's panicum (*Panicum hallii var. hallii*), buffalograss, common curlymesquite and silver bluestem. In contrast, slope sites are typically dominated by little bluestem, blue threeawn (*Aristida purpurea var. neallii*), slim tridens, hairy grama, tall grama, and, of course, seep muhly. One species that seems to cross over, without showing too much affinity for one site type over the other is tall dropseed (Dunlap, 1983).

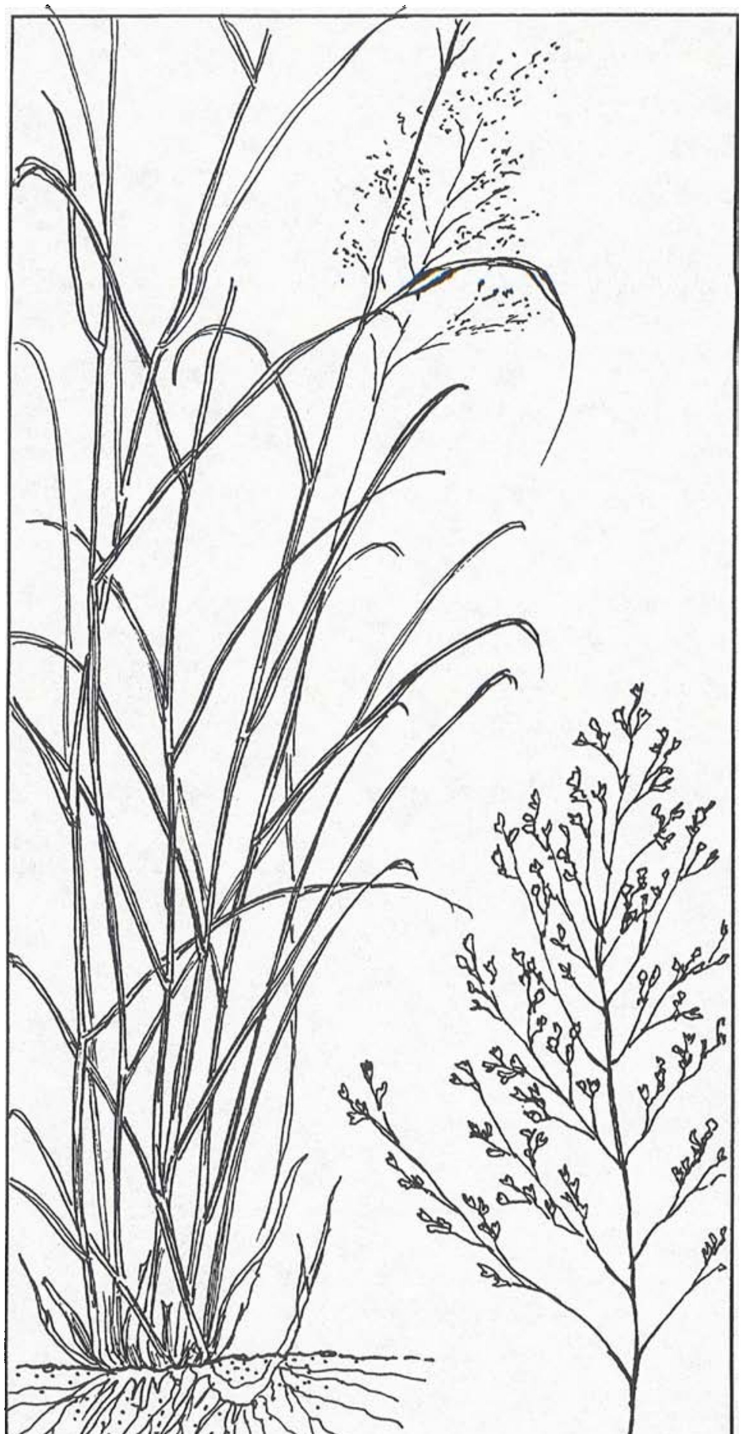


Big Bluestem
Andropogon gerardii



Little Bluestem
Schizachyrium scoparium

Yellow Indiangrass
Sorgastrum nutans



Switchgrass
Panicum virgatum

FACTORS INFLUENCING THE SPECIES COMPOSITION, DISTRIBUTION AND MAINTENANCE OF GRASSLANDS

The over-riding broad-brush factors controlling the species composition within grasslands are climate (especially temperature and precipitation) and soil characteristics. However, land-use history elements (especially the incidence of fire, cultivation and the intensity of grazing) also exert strong influences.

Grasses are well adapted to fire; grasslands are in part maintained by periodic fires that suppress the invasion of woody species. Timely fires also return nutrients to the soil which otherwise would remain bound up in leaf litter and other non-living plant parts. With the return of the nutrients to the soil, they are once again made available to the plants.

Also, with their growing points near or below ground, grasses are well suited to survive low-intensity fires such as those that come frequently enough to disallow significant build-up of leafy fuels. However, having discouraged range fires, humans have unwittingly encouraged the build up of fuels. So, when a fire does burn, depending upon the time of year, soil- and plant-moisture content, as well as other factors, the fire may burn so hot that it results in the destruction of the plants and loss of organic matter in the upper layers of the soil. The exposed mineral soil is made more vulnerable to the erosive forces of wind and water.

Cultivation of the soil has an obvious, deleterious impact on native species composition and community structure. What is less obvious, perhaps, is the loss of soil structure and the eventual loss of the native grass seed bank in the upper few inches of soil. For these reasons, abandoned fields can only over geologic time re-achieve the status and full functionality of native grasslands. However, with human assistance, formerly cultivated lands can become facsimiles with, at least, the aspect and partial functionality of an undisturbed native grassland.

Over-grazing can have similar results, albeit over a different time frame. Over-grazing results in species shifts, because grazing animals eat some species preferentially, causing those species to decline in abundance. The newly-opened niche caused by the disappearance of some species is occupied by other, opportunistic species, which are often less palatable. They, therefore, increase even more. If the intensity of grazing continues, then the cycle of decreased abundance and disappearance of some species followed by the increased abundance of others is repeated until the entire character of the site is changed.

THE ROLE OF GRASSES

Grasses, of course, function in many capacities and fulfill may roles. Principal among these are: soil formation, increased infiltration of water, erosion and sediment control, and forage.

Grasses in particular, of all plants, play an important role in soil formation. The decomposition of vegetative structures (e.g., roots, stems, leaves, etc.) over millennia contribute to an organic-rich upper soil horizon while also contributing organic acids that assist in the decomposition of the underlying parent material.

Likewise, by mitigating the impact of raindrops and the speed with which overland flow of water can occur, there is less runoff. Less runoff of water correlates with increased infiltration of water into the soil and increased infiltration contributes to the decomposition of parent materials. Furthermore, the shading effect of plants moderates soil temperatures, increasing the amount of time that water is retained in the soil.

Naturally, one of the greatest advantages offered by abundant grass cover is also the result of reduced runoff and mitigation of the impact of rainfall; namely, reduced erosion and sedimentation. The converse is also true, of course. Once the vegetative cover is reduced, topsoil losses accelerate - creating a downward spiral for the vegetative community. Fortunately, enlightened land management practices, such as a proper grazing regime, can maintain productive stands of forage grasses in good condition, resulting in the realization of all of the benefits described above.

COMMON NATIVE & INTRODUCED GRASSES FOUND AT THE BAMBERGER RANCH

There are four species that are dominant on tallgrass prairies that one can find in apparent refugia on the Bamberger Ranch. They are known as the *big four* - Big bluestem, little bluestem, indiangrass and switchgrass. Because each of these grasses is palatable to livestock they are preferentially grazed; therefore, wherever they are found in any abundance it is a sign of a grassland in good condition.

<u>Big Bluestem</u> - Big bluestem tends to prefer deep, calcarious-soiled sites; however, where there is a suitable water supply, it will grow on thin, limestone soils. It will grow up to six feet or more in height and produce roots of up to twenty feet deep. The plant is a perennial, and because it spreads by rhizomes as well as seeds, individual plants can cover an area of many square feet in size, albeit over a long period of time, because the rhizomes are short and spread slowly.

<u>Little Bluestem</u> - This perennial, warm-season bunch grass is often the aspect dominant (i.e., that which your eye sees most readily) on sites where it occurs. Another tallgrass prairie species, it is abundant on deep, blackland soils; however, it seems to be extremely adaptable to varying edaphic conditions and is one of the dominants on slopes where it is often associated with seep muhly. A fairly prolific seed producer, and aggressive colonizer of open sites, it is well suited as an erosion-control species.

<u>Indiangrass</u> - Indiangrass has a similar growth form as that of big blustem, but generally grows a bit shorter in our area, reaching heights of around five feet; however, it can range up to seven feet tall in seedhead. It, too, is a warm-season perennial with a rhizomatous growth habit, forming large clones. In late summer and early autumn, when most warm-season perennial grasses form seedheads, the characteristic golden inflorescence (i.e., seedhead) is very distinctive. It grows well in swales and at the toes of slopes, but also seems to do well on fairly steep terrain, lending itself well to use as an erosion-control grass.

Switchgrass - Switchgrass is a large bunch grass, growing from four to five feet in height, not including the seedheads. Also forming rhizomes, it is extremely well adapted to a wide variety of soil and moisture conditions, ranging from dry uplands to steam sides and even brackish marshes (Leithead, et al., 1976). The plant's large size; broad, open seedhead; and white mid-vein on its leaves combine to create a constellation of diagnostic characters. It should not be confused, however, with Johnsongrass (*Sorghum halepense*), an introduced, strongly-rhizomatous grass from Africa, which also has a distinctive white mid-vein on its leaves, but lacks the large, bunch grass growth habit.

There are two grasses in particular that can be considered indicators of a little bit of extra available water: Seep muhly and Lindheimer's muhly. Both are warm-season, perennial bunch grasses with gray-green leaves. However, that's where the superficial similarities end.

Seep Muhly - Found just below limestone benches where water emerges from seeps and low-flowing springs, seep muhly is a relatively low-growing grass: rarely achieving as much as three feet tall and usually no more than fifteen inches, excluding the seedhead. It creates a distinctive curly-leafed mound of narrow, in-rolled leaves, often dying out in the middle as the plant ages. Its inflorescence is thinly-flowered and wispy; almost invisible at times, except when the light is behind it, when it shines with a golden hue. It is often found in association with little bluestem, various threeawn grasses, slim tridens and tall grama: typical of thin-soiled, gravelly hillsides (fig. 3).

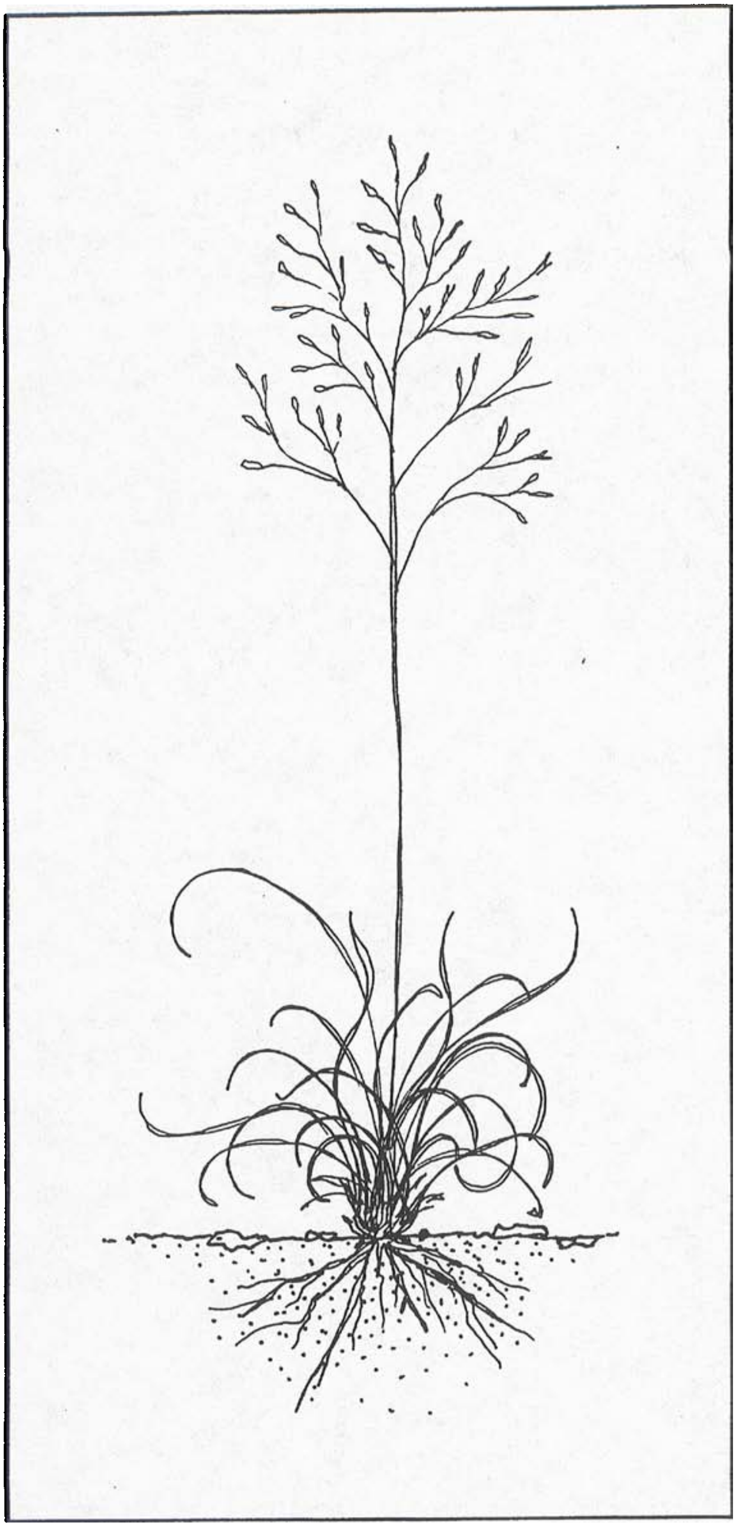
Lindheimer's Muhly - This grass is often found in swales with soggy ground. Its large bunches, commonly two to three feet in diameter and around four to six feet tall, are comprised of long, tough, cord-like leaves to thirty inches in length. Its seedhead is less open and more densely-flowered than seep muhly's, sometimes extending a foot or more above the leaves (fig. 3).

Some other common, native grasses include:

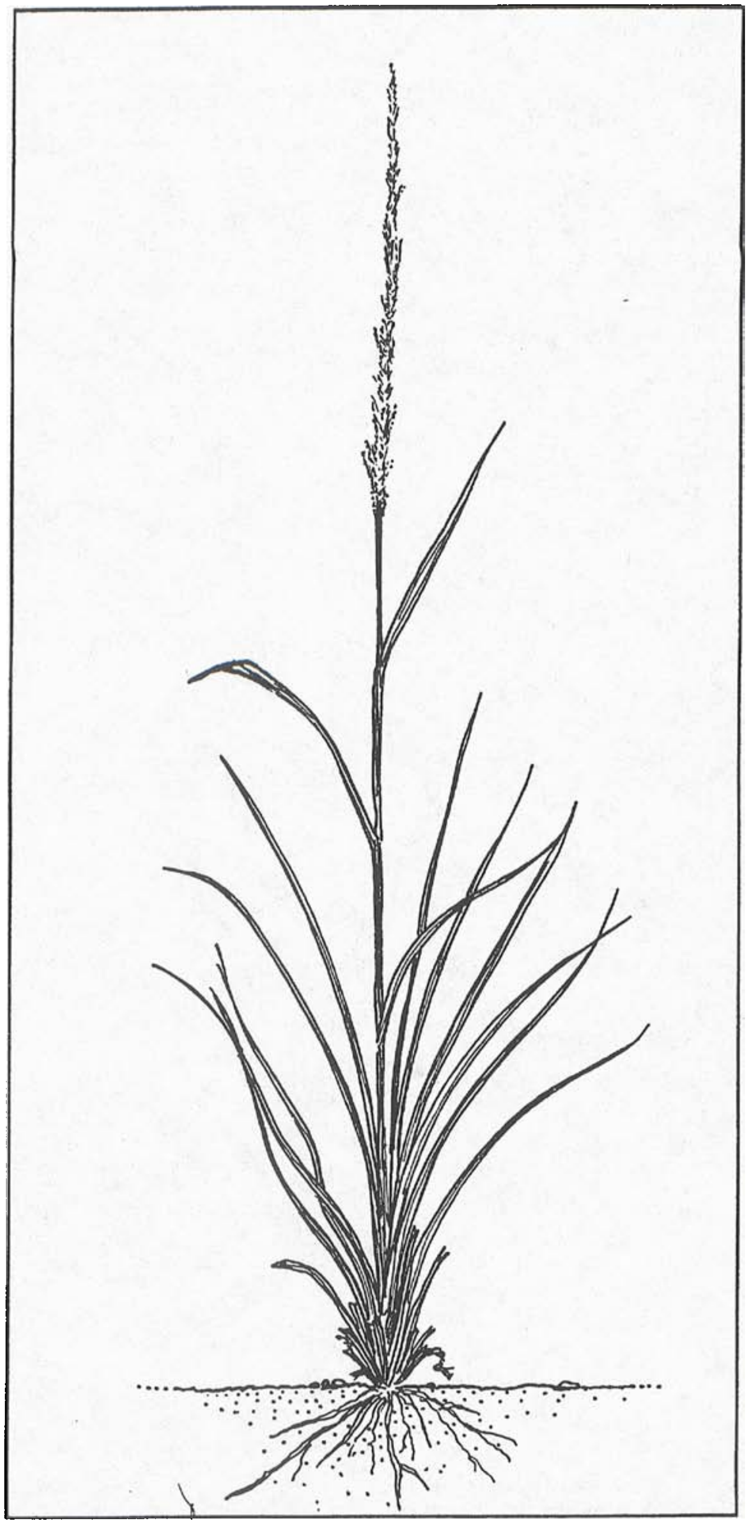
Texas Wintergrass - This is the only cool-season, perennial bunch grass described in this discussion. "Cool-season" means that it does most of its growing in the cooler, lower-light-intensity months, hence its common name of Texas wintergrass. Also, unlike warm-season grasses, it flowers in the spring. Its leaves, have a yellow-green appearance and are rough to the touch when one's fingers are run along them, because of many short, stiff hairs.

Sideoats Grama - This is the state grass of Texas, probably owing to its good qualities as forage. It is a rhizomatous midgrass (i.e., up to twenty inches tall). The leaves are flat, about a quarter of an inch wide, with fine, evenly-spaced, bulbous-based hairs along the margins near where the leaves join the stem. Upon drying, the leaves often form a curly mass that looks similar to wood shavings and take on a pinkish tone. The species gets its common name from the tendency of the spikelets to hang on one side of the flowering stalk (fig. 4).

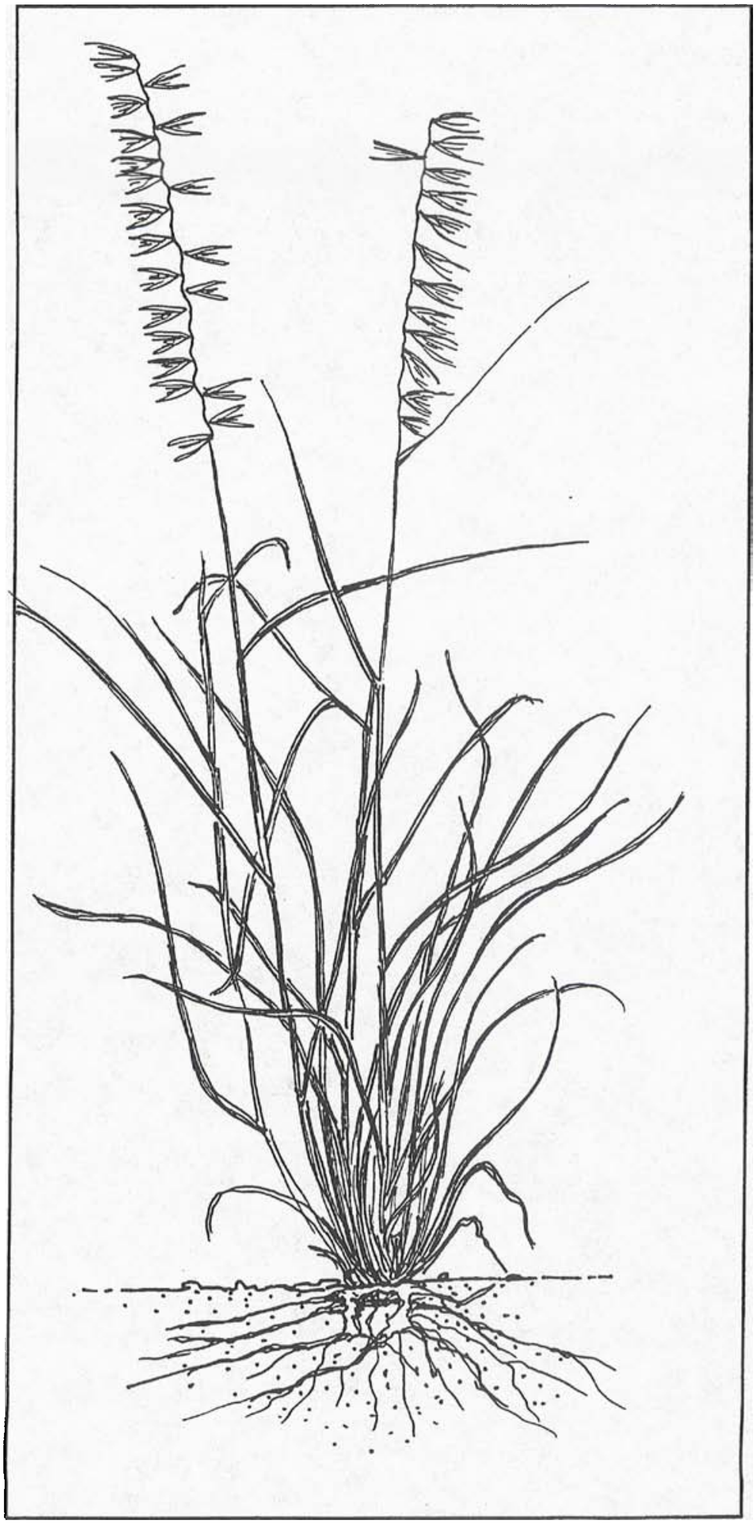
These next three species are often found together on flats sites with deep soils. All three are increasers under moderate grazing, replacing more palatable dominants of the climax community such as the big four mentioned above.



Seep Muhly
Muhlenbergia reverchonii



Lindheimer's Muhly
Muhlenbergia lindheimeri



Side-oats Grama
Bouteloua curtipendula

Silver Bluestem
Bothriochloa laguroides

Texas Grama - This grass is a small bunch grass. Similar to sideoats grama in appearance, but diminutive and few-flowered. Its leaves are much finer textured, too.

Silver Bluestem - This robust midgrass is distinguished by its prominent, silvery, fluffy-flowered inflorescence. It is a bunch grass and, although it often occurs solitarily, it can become the aspect dominant on a site (fig. 4).

Buffalograss - This classic sod-forming grass has recently begun to enjoy some prominence as a commercial turfgrass. With good reason. It is very drought tolerant, yet it can withstand periods of inundation by water, making it ideal as a ditch liner. It is slow growing and fine bladed, spreading by stolons (i.e., runners), lending itself to use as a residential and commercial lawn grass. Requiring full exposure to the sun, and growing low to the ground (achieving heights of six to eight inches), look for it in open flats, where it will form relatively large patches. Interestingly, this species has separate male and female plants.

Two species are noteworthy because of their position as both blessing and curse. Both species were introduced into Texas, principally as forage grasses, although both are used now for erosion control. Each of them, however, is an aggressive invader.

Bermudagrass - Bermudagrass (*Cynodon dactylon*) has been around in Texas for such a long time that most Texans think of it as native, but it originates from Africa. Like buffalograss, it is a turf former, but unlike its near-look-alike, it has underground rhizomes which contribute to its invasive character.

K-R Bluestem - King Ranch blustem (*Bothriochloa ischaemum*) also known as K-R bluestem is a native of the steppes of Asia. It is a bunch grass with the annoying habit of lying ever closer to the ground whenever it is subjected to grazing (or mowing, which mimics grazing). It is related to silver bluestem, but has a less robust flowering stalk, for which it compensates by producing an abundance of flowers and seeds repeatedly throughout the growing season if grazed or mowed. It is so aggressive in its spread by seed that it can soon overwhelm the local inhabitants and assume prominence on a disturbed site, giving a wavy-red hue to the landscape.

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Checklist of Birds of Selah

Margaret C. Campbell and Charles W. Sexton

INTRODUCTION

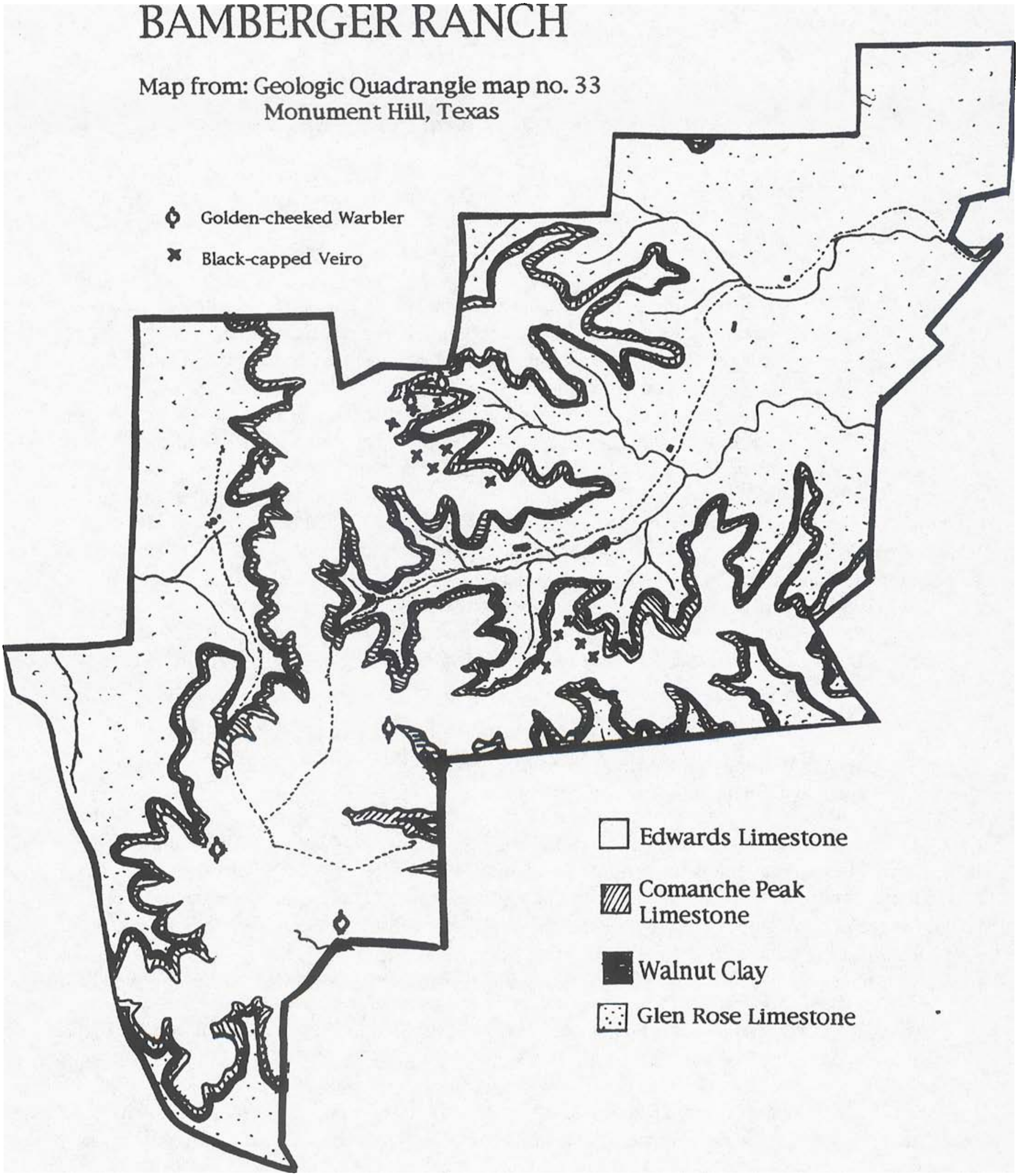
Much of the dissected region of the Edwards plateau known as the Hill Country, which describes the Selah terrain, has a large and varied population of birds for several reasons. First, there are Western birds which reach their Eastern limit and Eastern birds that reach their Western limit here. Thus found visiting Selah are both Western and Eastern Meadowlarks and Kingbirds, as well as Eastern and Mountain Bluebirds. Although the common hummingbird is the Black-chinned, we see Ruby-throated also. Second, the ranch is in the central flyway which means that many migratory birds briefly stop on their way between winter and summer homes, notably the warblers, vireos, flycatchers and thrushes. There are resident birds (cardinal, mockingbird, and vultures), winter visitors (ducks, kestrel), and a host of birds that spend some or all of the warm season here, many of whom also nest and raise young. From time to time a bird visits here that is out of its normal range, for example one juvenile White Ibis was seen in a shallow tank during August, 1996. Finally, habitat diversity, with a natural array of plants, including grasses, brushy species, and trees, on a varied terrain of canyons, creeks, tanks, valley floors, hillsides and plateau/hilltops insure that an interesting variety of birds can be sighted almost any time of the year.

We are fortunate to be home to two species of Federally listed endangered birds, the Golden-cheeked Warbler and the Black Capped Vireo. Both nest here and though their range overlaps, their specific habitats are quite different.

The Golden-cheeked Warbler needs the combination of Spanish Oak and Ash Juniper in its territory. Nesting material is the bark of the mature Cedar woven together with silken webbing from a caterpillar that lives in the Spanish Oak. The caterpillar itself is fed to the young when they hatch. The territory here at the ranch that suits their needs is found on the edges of the plateau/hilltops that are composed of the Fredericksberg Group of rocks (about 13 feet of Walnut Clay, 30 feet of Comanche Peak Limestone, and up to 125 feet of Edwards Limestone). A thick band of Spanish Oak dominated woods grow along the edges of the plateau/hills and where they are intersected by canyons the Golden Cheek finds its preferred habitat (fig. 1). Six nesting pairs were recorded in 1996 by Chuck Sexton.

The Black-Capped Vireo's needs differ from the Warbler even though it also finds its habitat in vegetation on the Edwards plateau/hilltops. Areas that were cleared and then allowed to develop a brushy cover dominated by the White Shin Oak about 3 to 5 feet tall provide the sites they prefer. During 1996, 12 territories were observed by Chuck Sexton, based on mapping

Location of Golden-cheeked Warblers and Black-capped Vireos



the singing territorial males. Females were sighted and it is presumed that many of these pairs were nesting.

The checklist of birds that follows was compiled over many years by a number of individuals and birding groups that visited the ranch. Groups from Bexar Audubon, San Antonio Audubon, Travis Audubon and Bastrop County Audubon have been frequent visitors and always submit a list of the birds seen to add to our volume of information about the ranch. The second author, Chuck Sexton made detailed searches for birds and nesting behavior on the ranch during the spring and summer of 1996. To all of the people who have contributed to this list, THANK YOU.

Selah Overall Bird List = 143 species
Probable and confirmed Breeding Birds = 53 species (listed in bold font)

Common Name	Nesting
Grebes	
Pied-billed Grebe	
Pelicans	
American White Pelican	
Cormorants	
Double-crested Cormorant	
Bitterns and Herons	
Great Blue Heron	
Great Egret	
Green Heron	
Night Heron sp.	
Ibises	
White Ibis	
Swans, Geese and Ducks	
Wood Duck	
Green-winged Teal	
Northern Pintail	
Blue-winged Teal	
American Wigeon	
Redhead	
Ring-necked Duck	
Lesser Scaup	
Vultures	
Black Vulture	?
Turkey Vulture	**x**

Common Name	Nesting
Kites, Eagles, Hawks and Allies	
Osprey	
Mississippi Kite	
Northern Harrier	
Sharp-shinned Hawk	
Cooper's Hawk	
Red-shouldered Hawk	?
Swainson's Hawk	
Red-tailed Hawk	**x**
Falcons	
Crested Caracara	
American Kestrel	
Merlin	
Peregrine Falcon	
Turkeys and Quail	
Wild Turkey	**x**
Northern Bobwhite	**x**
Cranes	
Sandhill Crane	
Plovers	
Killdeer	
Sandpipers, Phalaropes and Allies	
Solitary Sandpiper	
Spotted Sandpiper	
Upland Sandpiper	
Common Snipe	
American Woodcock	
Pigeons and Doves	
White-winged Dove	
Mourning Dove	**x**
Inca Dove	**x**
Cuckoos and Roadrunners	
Yellow-billed Cuckoo	**x**
Greater Roadrunner	**x**
Owls	
Eastern Screech-Owl	**x**
Great Horned Owl	
Goatsuckers	
Lesser Nighthawk	
Common Nighthawk	**x**
Common Poorwill	**x**
Chuck-will's-widow	**x**
Whip-poor-will	

Common Name	Nesting
Swifts	
Chimney Swift	x
Hummingbirds	
Ruby-throated Hummingbird	
Black-chinned Hummingbird	x
Kingfishers	
Belted Kingfisher	?
Woodpeckers and Allies	
Golden-fronted Woodpecker	x
Yellow-bellied Sapsucker	
Ladder-backed Woodpecker	x
Downy Woodpecker	?
Northern Flicker	
Tyrant Flycatchers	
Eastern Wood-Pewee	x
Acadian Flycatcher	
Least Flycatcher	
Eastern Phoebe	x
Vermilion Flycatcher	x
Ash-throated Flycatcher	x
Great Crested Flycatcher	x
Western Kingbird	
Eastern Kingbird	
Scissor-tailed Flycatcher	x
Swallows	
Purple Martin	x
Northern Rough-winged Swallow	
Cliff Swallow	
Barn Swallow	x
Jays, Magpies and Crows	
Scrub Jay	x
American Crow	
Common Raven	
Titmice	
Carolina Chickadee	x
"Black-crested" Titmouse	x
Wrens	
Cactus Wren	
Canyon Wren	x
Carolina Wren	x
Bewick's Wren	x
House Wren	

Common Name	**Nesting**
Muscicapids	
Golden-crowned Kinglet	
Ruby-crowned Kinglet	
Blue-gray Gnatcatcher	x
Eastern Bluebird	x
Mountain Bluebird	
Hermit Thrush	
American Robin	
Mockingbirds	
Northern Mockingbird	x
Waxwings	
Cedar Waxwings	
Shrikes	
Loggerhead Shrike	
Starlings	
European Starling	?
Vireos	
White-eyed Vireo	x
Black-capped Vireo	x
Yellow-throated Vireo	x
Red-eyed Vireo	x
Wood-warblers	
Tennessee Warbler	
Orange-crowned Warbler	
Nashville Warbler	
Yellow-rumped Warbler	
Black-throated Green Warbler	
Golden-cheeked Warbler	x
Black-and-white Warbler	x
Prothonotary Warbler	
Waterthrush sp.	
Common Yellowthroat	
Yellow-breasted Chat	x
Tanagers	
Summer Tanager	x
Cardinals, Grosbeaks and Allies	
Northern Cardinal	x
Blue Grosbeak	x
Lazuli Bunting	
Indigo Bunting	
Painted Bunting	x
Dickcissel	

Common Name	Nesting
Towhees, Sparrows and Allies	
Spotted Towhee (formerly Rufous-sided T.)	
Canyon Towhee (formerly Brown T.)	?
Rufous-crowned Sparrow	x
Chipping Sparrow	
Clay-colored Sparrow	
Field Sparrow	x
Vesper Sparrow	
Lark Sparrow	x
Savannah Sparrow	
Grasshopper Sparrow	
Fox Sparrow	
Song Sparrow	
Lincoln's Sparrow	
White-crowned Sparrow	
Dark-eyed Junco	
Blackbirds, Orioles, and Allies	
Red-winged Blackbird	
Eastern Meadowlark	x
Western Meadowlark	
Common Grackle	
Brown-headed Cowbird	x
Orchard Oriole	x
Carueline Finches	
House Finch	x
Pine Siskin	
Lesser Goldfinch	x
American Goldfinch	
Old World Sparrows	
House Sparrow	x

Notes:

Taxonomy follow AOU, 6th Edition + 40th supplement.
Bold notations indicate confirmed breeding evidence
(?) in the nesting column indicates uncertain evidence (not counted in total number of Breeding Birds)

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BLACK-CAPPED VIREO

GOLDEN-CHEEKED WARBLER

A Generalized Overview of Landscapes and Vegetation of a Traverse Across the Southeastern Hill Country, Travis to Blanco Counties, Texas

David H. Riskind

The field trip from Austin, Travis County, to the Bamberger Ranch, Selah, in Blanco County traverses the part of the state traditional called THE HILL COUNTRY. For good reason: the land is characterized by broad valleys and rolling, or gently undulating terrain. Here and there an escarpment or an entrenched small canyon is observable. Occasionally, there is a hint of rather flat, plateau-like feature.

From a coarse landscape scale, our traverse is at the boundary, ecotone if you will, of two great physiographic provinces: the Western Gulf Coastal Plain to the south and the Great Plains on the north (Hill, 1900). All terrains to the north and west of the Balcones Escarpment zone usually are included into the Edwards Plateau Natural Region and the Balconian Biotic Province (Blair, 1950). A bit finer landscape resolution categorizes our area into the Balcones Canyonland subregion of the Edwards Plateau (Fig. 1). The region is one in which there is obvious interdigitation of the various biotic and physiographic elements and, indeed Hill Country is more than apt as an overall descriptor. From the regional perspective, vegetation is influenced by the great grasslands of the Great Plains, the True Prairies of the Blacklands, the temperate deciduous woodlands and forests of the southeastern U. S., and the evergreen Madrean woodlands of the eastern Sierra Madre of Mexico.

I intend to give the reader a general overview of the landscape and vegetation in this short essay. Those with a hunger for more detail should consult a volume edited by Amos and Gehlbach (1988), which includes a very good bibliography. This work, EDWARDS PLATEAU VEGETATION: Plant Ecological Studies in Central Texas, and especially the introductory chapter (Riskind and Diamond, 1988) provides the best summary of the vegetation of the region available.

From the perspective of vegetation structure our transect includes grassland, savanna, woodland and forests. Depending on substrate, grasslands vary from mixed-grass to tall grass grasslands; woodlands may be either deciduous or evergreen depending on topoedaphic conditions. At the outset we should state that the natural vegetation, indeed the landscape, has been heavily modified since initial European settlement. Woodlands have been converted to grasslands composed of alien species, native grasslands have been converted to overutilized short grassy swards, row crops or tame pasture. Virtually all community types have been fragmented, cedar (juniper) woodlands have been harvested for posts or have been systematically attacked to

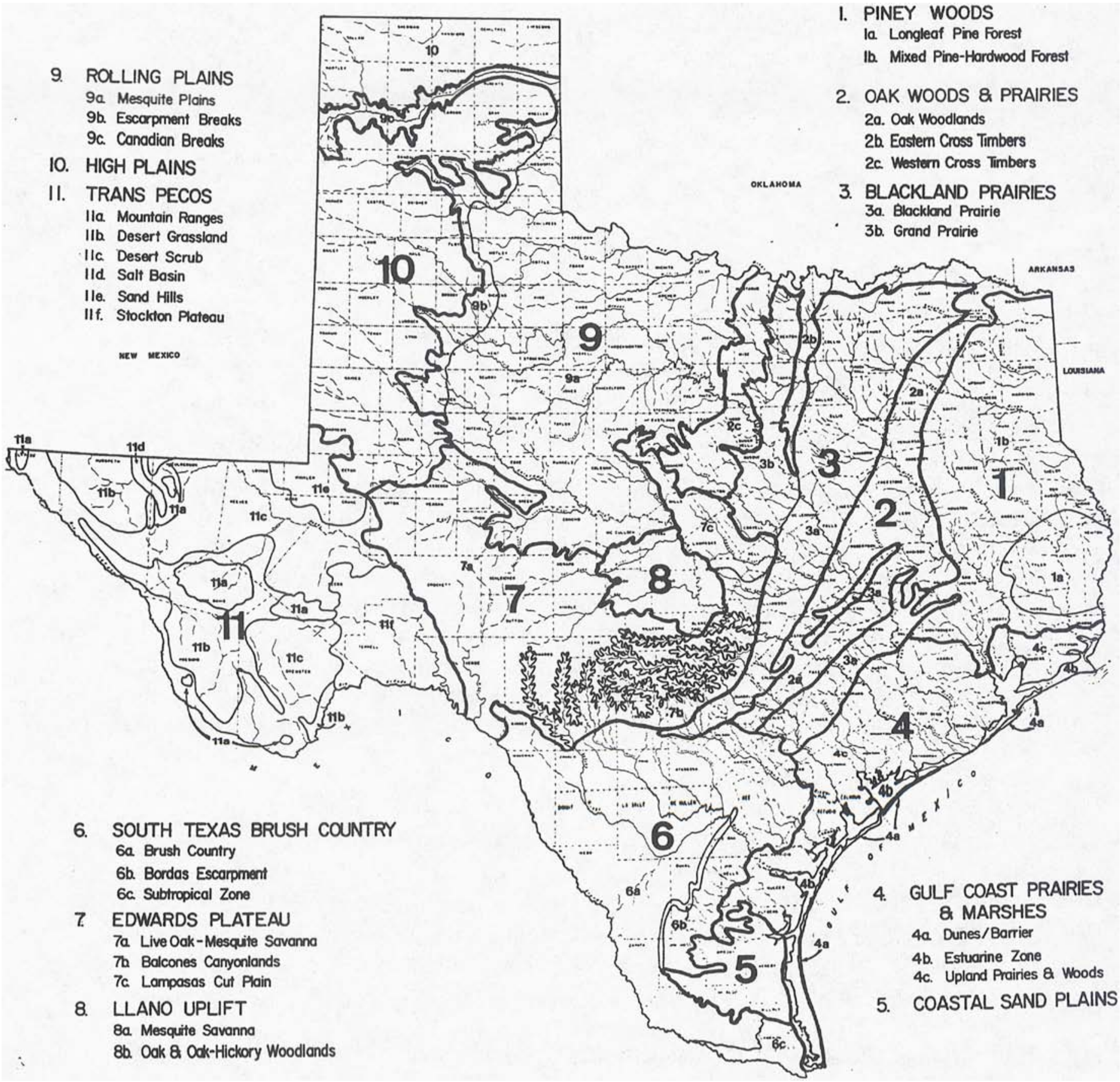

Figure 1. Natural subregions of Texas (from L.B.J. School of Public Affairs, 1978).

increase productivity and to repulse what many have characterized as an "alien invader" that destroys grasses and sucks land dry! The message is simply that the contemporary landscape is greatly changed both in structure and composition from that which should occur 'naturally'. Only in a few places where special care has been taken or where a land manager has the appropriate dedication can one see the natural vegetation potential of the region.

While the Balcones Canyonlands in general is an area of relatively high species diversity, our transect, does not necessarily reflect this. Sheltered, deeply incised canyons have a significantly more mesic (moist) microenvironment and coupled with the buffering effect of the canyon environment itself, tend to support most of the rare (restricted in distribution) and endemic (occur here only) species of plants and animals. Indeed such environments contribute to the noteworthy species diversity and richness of the canyonlands.

Our field trip route crosses an especially open, undulating landscape (Fig. 2). Steep canyons with their entrenched drainages and steep escarpments are on the margins of our transect. We traverse the more open ridges, drainage divides and more open 'mature' valleys as we proceed to the easternmost contiguous outlier of the Edwards Plateau on the Bamberger Ranch (See Woodruff, this volume).

Virtually all of the soils along our traverse were derived from limestone or marl, thus the vast majority of regoliths and soils tends to be clayey and alkaline. There are exceptions here and there where there are siliceous sands or gravels (of quartz or chert), paleosols in karst features, or along drainages where materials have been transported from upstream where there are granitic or quartzose parent materials. Recall that our track is very near the southern edge of the Llano Uplift , consisting of complex, fault-bound masses of Paleozoic and PreCambrian rocks. The edge of this complex terrain easily can be observed at the falls overlook at Pedernales Falls State park at the end of RR 3232 just north of our route.

Relatively flat, gently rolling (= undulating) landscape tends to support a plant community often called live oak savanna. You can still see vestiges of this community. It would have appeared as a grassland dominated by little bluestem and Indiangrass, occasionally big bluestem, as the matrix, with individual or mottes of plateau live oak here and there. Live Oak Savanna occurs as well on many of the broad terraces on the margins of streams. The Blanco County champion live oak, noted along Miller Creek Road along our field trip route, occurs in this type of setting. Today, one is likely to see thickets of liveoak (the species root sprouts), short grasses dominated by Texas grama, KR bluestem (an alien species), baccharis (called Roosevelt weed by older folk), scrubby cedar and all manner of other plant species that prefer a disturbed setting. This savanna was maintained naturally by drought and fire and I speculate that a plant pathogen, oak wilt, also helped keep the density of oaks low. Might this help explain why oak wilt is so virulent and destructive in some circumstances in today's landscape?

Thinner soils on slopes and narrow drainage divides, especially on dryer exposures are clad in Juniper (cedar) and live oak woodlands. Under normal (natural) regimes, grasses such as little bluestem abound as well. Broader ridges tend toward the savanna as noted above.

Wherever the Glen Rose is encountered, both steepness and exposure are important factors that yield completely different vegetation. On steep south and west exposures, an evergreen

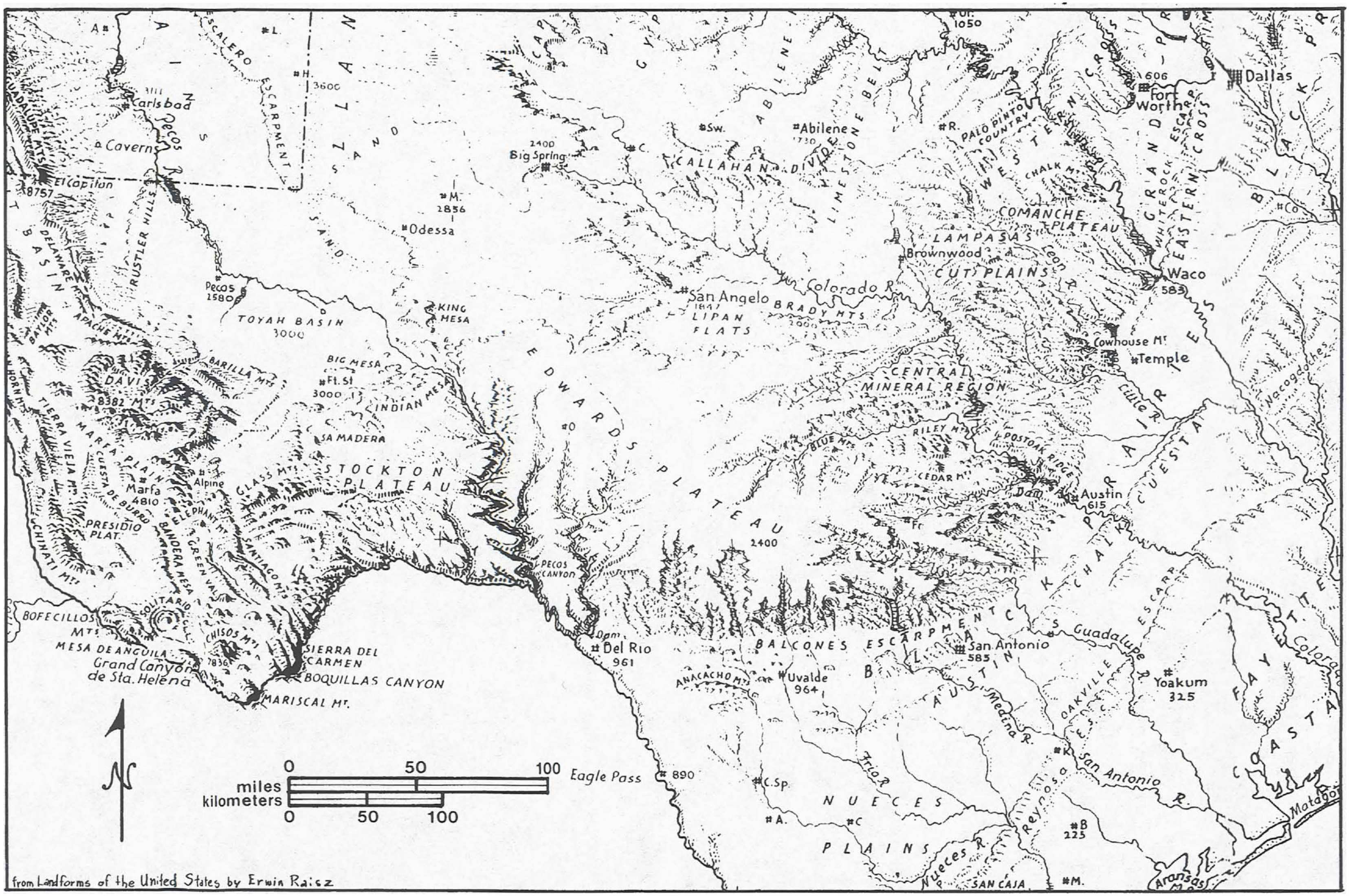

Figure 2. Landforms of the Edwards Plateau Region and adjacent areas (from Landforms of the United States by Erwin Raisz).

woodland (juniper -oak) with little herbaceous or grassy component prevails. Often this habitat is altered and cleared (principally of cedar) and live oaks and perhaps occasional other trees or small shrubs, are left. Vegetation on very steep slopes is often left intact. South and west exposures are juniper-oak, while north and east exposures are usually more diverse deciduous woodlands with Texas oak often dominating. Texas redbud and Mexican buckeye are conspicuous in early spring. Trying to figure out the composition of many of these landscape features is often obscured by historic and current land use practices.

Occasionally slopes are very open and grass dominated. Bunch grasses such as little bluestem, various Muhley's can often form a solid sward. In certain seasons wildflowers are abundant and in winter one may be surprised by abundant lady's -tresses orchids! Such sites are called glades by some; their vegetation composition seems to be controlled by either an abundance or a deficit of available moisture. Recent research discussed by Wilding (this volume) demonstrates that the "stair-stepped" topography typical of much of the Hill Country uplands contains dramatically different soil moisture regimes. The steeply sloping "risers" contain relatively thick soils having high moisture retention and support an abundance and diversity of native grasses. In contrast, the nearly flat "treds" exhibit thin, droughty soils that support sparse grasses and forbs. Blue-green algae, Nostoc, prospers here and often dominates the ground cover.

Broader deep soil alluvium-filled valleys usually support cedar elm-hackberry-oak woodlands. One is likely to see either Mexican plum of hog plum in flower during spring. Pecan trees occur locally where soil is especially rich and well watered. Most of these sites have been converted to managed pastures or croplands.

Virtually all the intermittent drainages have as an important component on their margins a tall grass called swithgrass. This robust bunch grass prefers such habitats but it will not tolerate continuous grazing. Where land use and conservation allow, eastern gamagrass, a relative of corn, is present. Such high energy environments as well as most of the permanent streams in our traverse are dominated by sycamore, a large deciduous tree. It is ubiquitous in and along drainages with a rock substrate. Curiously, baldcypress is absent along the smaller streams except where planted by modern humans. Baldcypress occurs along the Pedernales and Blanco Rivers but has been unable to colonize, perhaps owing to limiting habitat factors along Miller or McCall Creeks.

As we proceed westward and as the elevation increases we see steeper hillsides with their cap of Edwards Limestone and with their flanks of various marly or clayey members, e. g. Walnut Formation. These slopes have the richest plant diversity of all habitats along our traverse. Here Texas oak dominates, but Texas ash, escarpment chokecherry, madrone, Arizona walnut, basswood, hackberry, elm and a diversity of other trees and shrubs form a very nice escarpment woodlands (or, since their canopies intermingle, we could just as easily call them forests). One of the rarer, endemic plateau shrubs, Sycamore-leaf snowbell, occurs in this community type. Madrone, a species at home in the mountains of west Texas, other southwestern states and Mexico, venture to the eastern extreme of their range here as well.

From the 'toe' of these slopes onto the surface of the underlying Glen Rose formation, a savanna or very open woodland community occurs; in their relatively undisturbed aspect, mid and tall grasses predominate with little bluestem as the binding dominant at least in the contemporary scene. Where good drainage and slope and aspect conditions permit, twist-leaf yucca, sacahuista, and sotol occur in a grassland matrix. These are not desert plants but stem succulents that require good drainage and protection from hard freezes.

Notice particularly all the downed and broken branches especially within the Texas oak woodlands. This is severe ice damage resulting from of a January 1997 ice storm in the Hill Country. Texas oaks with their persistent leaves, the evergreen live oak, and Texas madrone, and to some extent Juniper provided a ready surface for the ice to adhere. the extra weight snapped the branches with the brittle madrone being especially susceptible. Such ice storms together with wind throw are the primary ecological factors driving successional process in some woodlands west of the Balcones Escarpment zone.

At the highest elevation of our traverse and upon the relatively flat uplands on an outlier of the Edwards Plateau we find not a grassland, as one may have expected, but a post oak woodland. Cedar elm occurs here and there as well. Although on Selah much of this woodland has been cleared to increase grass production, woodland patches still remain on the very upper margins of the plateau. The soil and regolith contains a very high percentage composition of chert, this having been weathered from the Edwards Limestone. Soil pH is neutral to perhaps slightly acidic and thus is favorable for development of post oak woodland. There also may be some blackjack oak where there is a sandier element.

In other portions of the actual plateau where grasslands predominate one occasionally will find small stands of post oak and or cedar elm.. More than likely these trees are localized on a paleosol within a filled karst feature.

Even though the landscape has been greatly modified with profound changes of vegetation composition and structure, and habitat has been fragmented by settlement and land division for at least one hundred and fifty years, there still remain many clues as to the natural landscape fabric. One can even look at contemporary aerial photographs and clearly discern grasslands from savanna from evergreen and deciduous woodland and forest. This overview should provide you a clearer view and at least a more complete understanding of some of the basic natural and human caused processes which yield our contemporary landscape on the southeastern margins of the Texas Hill Country.

I gratefully acknowledge the assistance of C. W. Woodruff, Jr, who, in addition to providing good company on our dry-run field trip for this proceeding, saw to it that my cavalier use of geological terms for this essay was kept to a minimum. My thanks also to David Bamberger and Margaret Campbell for their hospitality at Selah.

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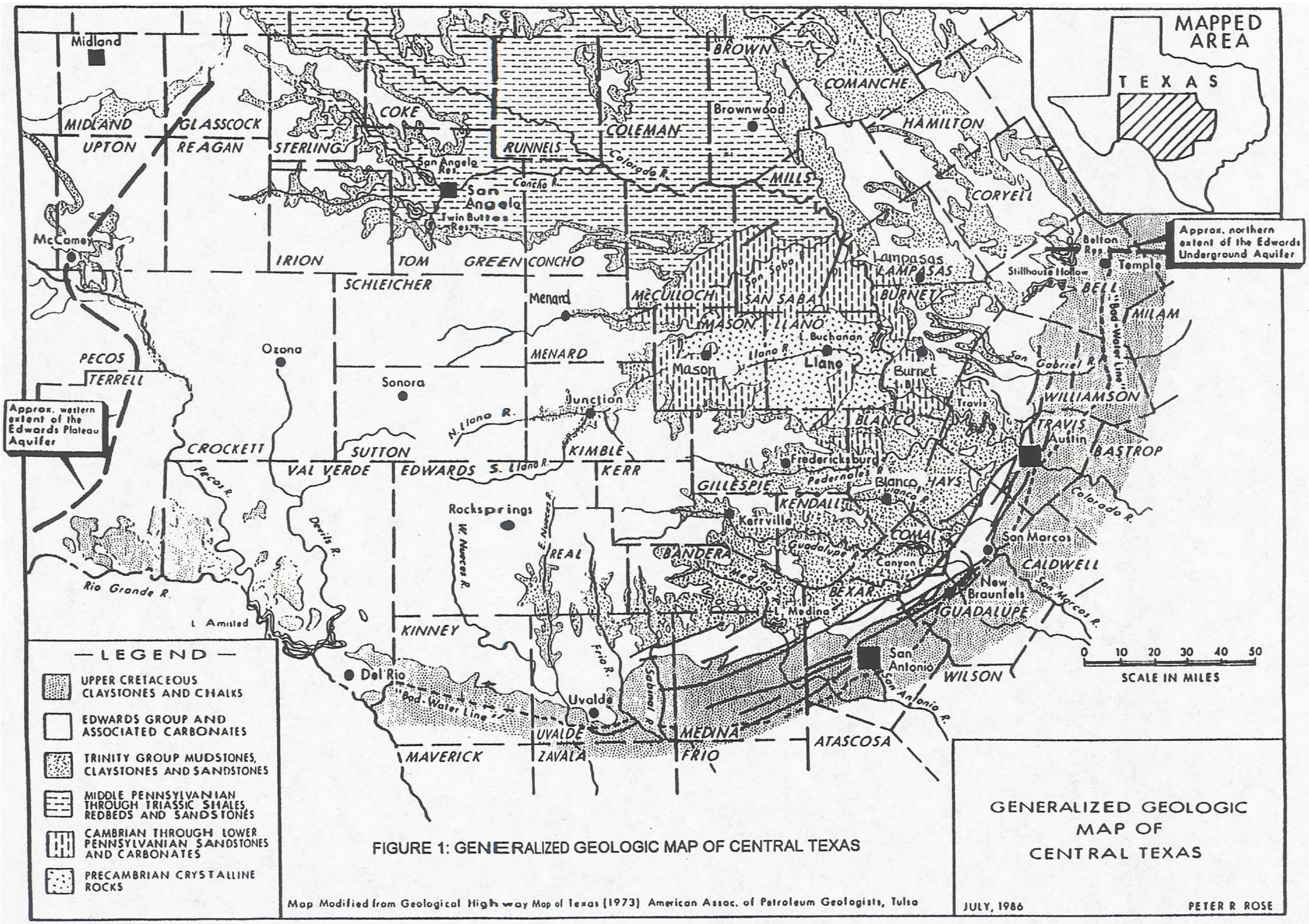

FIGURE 1: GENERALIZED GEOLOGIC MAP OF CENTRAL TEXAS

Tribal Conflict and Vengeance in the Frontier Hill Country

Peter R. Rose

Tribal behavior has been described as "treating people outside the group much differently than people inside the group." Although generally perceived as a primitive trait, tribal patterns of behavior occur even in our late 20th century world, even in societies perceived to be civilized and advanced. Often it is the tribal elders who command or define the attitudes that beget tribalism, whereas it is the young men, the warrior class, who carry out violence between tribes.

During the middle 1870's, frontier conflicts in the Texas Hill Country involved three diverse groups, whose behavior was, in most respects, tribal. Only one of the groups was native American, and it actually consisted of many tribes.

The lifestyles and cultures of all three groups—and thus the character of their conflicts—were strongly influenced by the geology, hydrology, and geography of central Texas. Two geologic features dominate the region: the Balcones Fault Zone to the east and south, and the Edwards Plateau, an immense semi-arid tableland covering about 25,000 square miles, on the west (Figure 1). Headward-cutting streams dissect the Plateau, creating deep canyons and complex topography around its margins, with springs from the Plateau aquifer feeding eastward-flowing tributaries and small rivers. The high interfluves are held up by resistant Edwards Limestone. This dissected landscape is a characteristic one which we know as the Texas Hill Country.

North of the Edwards Plateau, in Central Texas, lie complex terranes of the Llano Uplift, with common sandy soils derived from basal Cretaceous and Cambrian sandstones, as well as carbonate soils based upon Pennsylvanian, Ordovician and Cambrian limestones. Farther to the north are rolling prairies underlain by Carboniferous sandstones, shales, and redbeds. The rolling prairies extend northward across Red River into southern Oklahoma. They are bounded on the west by the Caprock Escarpment, the eastern edge of the Llano Estacado.

This physiography and hydrology exerted a profound influence on the frontier history of the Central Texas region. Early settlement of the Hill Country depended upon reliable water, arable land, and protection from Indian attacks. The absence of permanent water on the Edwards Plateau prevented agriculture and settlement there until the utilization of the windmill in the 1880's and 1890's. Before 1880, the Edwards Plateau was an uninhabited savanna that reached far eastward into the established settlements of Central Texas, a wilderness highway used by bands of marauding Comanches coming down from the High Plains, and by renegade Lipans and Kickapoos raiding eastward from protected villages in Coahuila and Nuevo Leon.

As the Indian danger diminished in the 1870s, the Edwards Plateau began to harbor outlaws, especially in those locations which previously had been most vulnerable to Indian attacks. Desperados were attracted to such communities by (1) the sparseness of permanent inhabitants; (2) the absence of organized county governments (and thus law); (3) the abundant hiding places provided by the dark, well-watered coves and hollows around the dissected margins of the Plateau; and (4) the adjacent wilderness of the Plateau proper, into which they could flee when lawmen did venture into the region.

Contributing to this pattern of lawlessness was the advent of the range-cattle business, in which free-ranging livestock was gathered on the open, unfenced range, for eventual shipment to Kansas. A vague and lenient range-law actually promoted conflict by making theft easy within the course of conventional gathering and droving.

Many Hill Country communities were long delayed in becoming organized and law-abiding (Figure 2). Different ethnic groups, behaving tribally, found themselves on opposite sides of the law. Vigilance committees sprang up where generally law-abiding citizens had lost patience and faith with legal authorities, and they abused the very law they preferred and professed to uphold. Other groups, especially those involved with cattle-gathering, skirted and abused an ill-defined range-law, but otherwise maintained lawful God-fearing societies. In some cases, confederations of outlaws actually outnumbered lawful citizens, and even gained control of county governments through intimidation and collusion. In many counties, such as Burnet, Lampasas, Llano, Mason, Menard, and Kimble, stable, law-abiding government and society were only established after extended power struggles, which usually, as in this case, required repeated intervention by the Texas Rangers. This paper is a narrative account, based upon documented contemporary reports, of such a frontier conflict. Readers will note that many of its themes have become classic scenarios of Hollywoodís western movie genre.

There has been a cemetery beside Miller Creek for nearly as long as there has been a Miller Creek community in central Blanco county. Among the earliest gravestones is the one commemorating the final resting place of Thomas Phelps and his wife, who were murdered by Comanche Indians in July, 1868, while fishing nearby on Cypress Creek. A few yards away is a flat slab, marking the grave of Scott Cooley, Texas Ranger, born 1855, died 1876.

Most of the recorded names in the Miller Creek Cemetery, especially the older ones, are of Scotch-Irish origin—Phelps, Mattox, Friend. Only one Cooley. Those early Blanco County settlers arrived in the Texas Hill Country by way of the traditional southern migration route, spanning three or four generations—Virginia, Carolina, Tennessee, Alabama, Missouri. They brought with them characteristic cultural attributes—clannishness, fundamentalist religion, a fierce and stubborn independence, old-testament vengefulness, fervent loyalties, and traditions of cattle droving and whiskey making. Yeoman farmers mostly, with few slave-holders among them, but otherwise strongly Southern in outlook. Most of those who fought in the Civil War wore Confederate gray.

The Hill Country was mostly open then, a climax grassland, rolling and well-watered, with timber along the draws and streams. A new settler could locate upon an alluvial terrace, plant a corn patch and a kitchen garden, draw water from nearby springs, build a stake cabin from local timber, and run cattle in the adjacent hills. In time, he could sink a shallow well, and set up stake-and-rider fences or stone walls close by the homestead. Otherwise, there were no fences. The thick turf, diverse tall range grasses, and temperate climate appeared to make the country ideally suited for the raising of beef cattle.

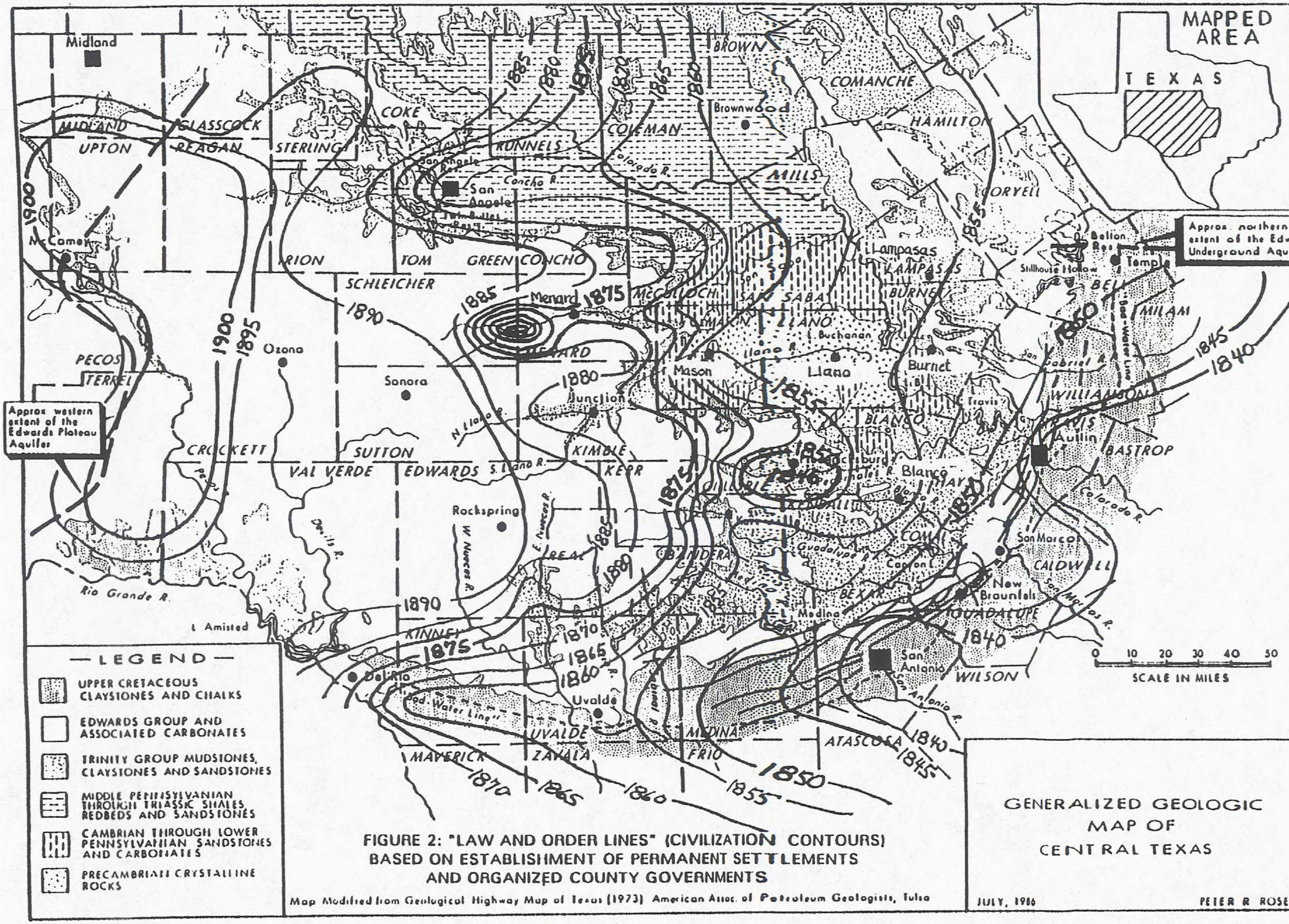

FIGURE 2: "LAW AND ORDER LINES" (CIVILIZATION CONTOURS) BASED ON ESTABLISHMENT OF PERMANENT SETTLEMENTS AND ORGANIZED COUNTY GOVERNMENTS

When the surviving Confederate veterans returned in 1865, many began to gather the wild cattle that had multiplied in their absence, and to deliver them, by overland droving, to emerging new markets at Kansas railheads. Those who did not join the trail herds made it their business to supply those entrepreneurs and contractors who did.

Fredericksburg was settled by German immigrants in 1846. By 1861, when the Civil War began, German settlers had spread out, northwest to Fort Mason, northeast to Llano, east to what is now Stonewall, 20 miles west of Miller Creek. At the time Fredericksburg was founded, it lay about 60 miles west of the frontier. By 1861, however, the line of westernmost permanent settlements had caught up and even moved a little beyond.

The German immigrants were farmers, mostly. They came not as new Texans but as new Americans. They came for land, and to escape military conscription and ongoing political unrest connected with early attempts to unify Germany. They were predominately Lutheran and Catholic, and they had a unifying language and strong cultural traditions. They were well educated, and they formed a cohesive and separate community. Following their leader Johann von Meusebach, they made a treaty with the Comanche tribes, which was mostly honored for a generation or more. Nevertheless, they formed their young men into local militia bands, called "minutemen," to guard and patrol their settlements.

By 1861 they had adapted to the country. The stock farmers among them had begun to improve their herds through the introduction of European bloodlines. Very few of them were slaveholders. Many, in fact, held strong moral views against slavery, and many were Union sympathizers. But in respect to the approaching Civil War, it was not their fight, and most simply wanted to be left alone.

In 1862 the Confederate military authorities in San Antonio wanted recruits. Conscription was an institution the German immigrants had already fled once. Now it had reappeared, and for a cause most found abhorrent. The young German men gathered and headed for Mexico, where many sat out the war. But about 35 did not make it across the Rio Grande—they were set upon by a thinly disguised partisan "Home Guard" on the West Nueces in August, 1862 and massacred. Afterward, the Confederate military authorities condoned guerilla bands in the Hill Country, who preyed viciously upon German settlements.

But Appomattox finally came. Afterwards, for eight years, a harsh Federal military occupation supported carpetbagger state governments, who remembered and rewarded loyal unionists. The Germans thrived. The returned Confederate veterans watched and waited. Finally, in early 1874, Democrat Richard Coke defeated the Republican incumbent Governor, E.J. Davis. The era of reconstruction was over.

The third contingent in our story comprised many tribes. Indigenous Lipan Apaches, who gradually withdrew to Mexico and transPecos Texas from which they—and some Mescalero Apaches—raided eastward. Comanches—Penatakas, the southern group, whose ranges lay just north of the Hill Country, and the even fiercer Northern Comanche, especially the Kwahadis and their Kiowa cousins, who raided southward and eastward from the High Plains, and periodically, from government-sanctioned safe-havens in southern Oklahoma. They came like ghosts, using the elevated limestone interfluves of the empty Edwards Plateau as warpaths into the vulnerable

Hill Country settlements. Then, after 1865, Kickapoos, raiding north eastward from protected enclaves in Nuevo Leon, in revenge for the perfidy of irregular Confederate Home-guard attacks during the Kickapoosí peaceful migration to permanent settlement in northern Mexico. Even the German settlers began to suffer losses from Indian raids.

Raiding was a major cultural activity of the Plains Indians. It had been going on for centuries between the various neighboring tribes, and against Mexican settlements deep into Mexico. The influx of frontier Texas settlements provided yet another target during the middle 19th century. Raiding was the special purview of the young men, the time-honored way by which the young braves could demonstrate their manhood. And the booty, including horses and captives, represented not only negotiable wealth, but tangible evidence of masculine courage and prowess as well.

Frontier defense was substantially weakened during the Civil War. Raiding forays multiplied, especially against the Scotch-Irish Texians. The frontier line wavered, fragmented, and retreated eastwardly. The death toll from Indian raids skyrocketed. First the Confederate government dithered, making feeble defense efforts. Then the Carpetbagger governments dithered. The Scotch-Irish settlers suffered, and seethed. And waited.

One of the very first acts by incoming Governor Richard Coke in early 1874 was to establish the Frontier Battalion of the Texas Rangers—six companies of 40 mounted, well-armed policemen, each commanded by a Captain, with a Lieutenant, one or two sergeants and several corporals. Major John B. Jones organized and oversaw the Frontier Battalion, reporting to William Steele, the Adjutant General. Its primary purposes were to guard the western frontier, from the Rio Grande to Red River, and to pursue and punish Indian war parties who raided frontier settlements.

Concerted military action by the U.S. Army in late 1874 and early 1875, especially the Palo Duro campaign of Col. Ranald MacKenzie, put an end to much of the Comanche raiding into Central Texas, although occasional forays continued through 1876 from Oklahoma and 1878 from Mexico.

So, beginning in late 1874 the Frontier Battalion began to turn its attention eastwardly, to the organized outlaw bands who had gathered and consolidated in various settlements along the frontier. Many were engaged in wholesale livestock theft, some through an informal relay system (called the "chain gang") by which stolen horses and cattle found their way to Mexico or to Comanchero traders on the High Plains. Other simply gathered loose cattle from the open range, without regard to ownership or brand marks, and delivered them to herds bound for Kansas. This pattern repeated all along the frontier. Prominent among such rustlers in Central Texas was the D.W. Roberts gang, operating primarily in Burnet, Lampasas, Llano, Mason, Blanco and Gillespie counties. Another repeated pattern in response to such lawlessness was the formation of several vigilance committees, which sprang up spontaneously to counter it.

Company D was a Blanco County outfit, captained by old Indian-fighter Rufus Perry. Dan Roberts (no known relation to D.W. Roberts) was Lieutenant. N.O. ("Maje") Reynolds was sergeant. They were up to full complement by May, 1874, and took up station on the San Saba River, west of Menard. One of the privates in Company D was Scott Cooley, then 19 years old.

Cooley's early history is obscure. He seems to have been abandoned by his father, who was killed in a gunfight in Palo Pinto County in 1872. But, as a boy, Scott Cooley was recovered by trade from plains Indians by Tim Williamson, a young Hill Country cattleman, while Williamson was returning from a cattle drive. The price was one horse. The year would have been about 1868. Williamson returned home to Burnet County with the boy, who later fell ill with typhoid fever and was nursed back to health by Williamson's wife Mary (nee Johnson). One of Mary Johnson's brothers had been killed by the same Comanche raiding party that had killed Thomas Phelps and his wife, and a younger brother had been captured, but rescued days later near Fort Mason. And four Johnson relatives had been killed and mutilated by 15 Comanche raiders about six months earlier.

Scott Cooley forgot neither his gratitude nor his admiration for the Williamson family. Considering this background, we are safe in surmising that young Scott Cooley, of warrior age and inclination, was thoroughly familiar with Indians—and loathed them.

One of the first actions involving Company D and Private Scott Cooley was a 2-day pitched battle in late June, 1874, near Jacksboro. The battle of Lost Valley pitted 35 Texas Rangers—most frontiersmen in their late teens and early 20's—under the direct command of Major John B. Jones, against about 250 Comanche and Kiowa warriors under the Kiowa war chief, Lone Wolf. The Rangers got the worst of it, with two men killed and many wounded, plus the loss of half their horses. But young Scott Cooley collected a tangible war-trophy, a strip of hide from a dead Indian, tanned it, and thereafter used it as a razor-strop. Some of his fellow rangers thought Cooley's trophy was barbaric; others found it less objectionable. Two of Cooley's Lost Creek Ranger comrades, Dan Roberts and Maje Reynolds, may have been among the latter.

Scott Cooley mustered out of Company D in December, 1874, with an honorable discharge, and began ranching along the San Saba River, gathering loose cattle for himself and/or his employers, whoever they were. So far as we know, his activities there were entirely legal and above board.

Cattle rustling, primarily involving the D.W. Roberts gang of Llano and Burnet Counties, as well as loosely allied associates and imitators, was getting out of hand. German ranchers in Llano and Mason counties had complained repeatedly during 1872 and 1873 to both state and county authorities, to no avail. Llano and Burnet County law officers would not honor Mason County complaints.

Finally, by early 1874, the German faction had elected a young and militant German, Daniel Hoerster, as County Hide Inspector, and his young friend, John Clark, as Sheriff. They began to crack down on the cattle gatherers. In late July, 1874, Clark, Hoerster, and a large posse of young German minutemen surrounded and captured D.W. Roberts and 10 members of his gang of rustlers along the Llano-Mason county line and carried them to Mason where they were confined in a tiny jail during high summer for several days. Then they were brought before the Justice of the Peace, tried, and found guilty of cattle rustling, and their cattle were confiscated. The men were not released until money could be brought from Burnet to pay their sizable fines. Then they were publicly humiliated—hooted out of Mason by a jeering mob composed primarily of German ranchers, minutemen, and townsfolk. John Baird and his brother Moses were two of these Burnet County cattlemen.

The rustling continued. In February, 1875, Clark and Hoerster, with another posse captured six rustlers in northern Mason County, including Charley Johnson (Tim Williamson's brother-in-law), and a young boy, and brought them back to Mason where all except the boy were jailed. Several nights later, a hooded mob relieved Clark's Deputy John Worley of the jail keys, removed all five prisoners, and escorted them to a live oak grove about a mile southeast of the town square and proceeded to hang them.

A rescue party made up of townspeople, and accompanied by Lieutenant Dan Roberts (who happened to be in Mason) followed close behind. A shooting melee took place in the darkness and three of the five prisoners, already strung up, were shot and killed by the lynch mob. One rustler, strangling at the end of his rope, was cut down and saved, and later released. The fifth, Charley Johnson, escaped in the confusion. The participants in the lynch mob were never identified, but it was common knowledge that they included most of the German activists in the community.

Beginning in the late 1860's, Johann von Meusebach began to colonize and develop a community on his land at Loyal Valley, about halfway between Fredericksburg and Mason. Most of the settlers who took up the small homesteads there were Scotch-Irish, involved in cattle-gathering. One such family was Tim and Mary Williamson and their two young children, who took up a lot there in about 1872. Another cowboy named George Gladden was one of their neighbors.

In March, 1875, Williamson was served with a complaint filed by Dan Hoerster, accusing him of driving off one of Hoerster's cows. Williamson came to Mason on his own accord and unsuccessfully attempted to settle the matter. In May, 1875, just before the spring term of District court, Deputy John Worley, acting on Sheriff Clark's orders, went to the ranch of Karl Lehmberg, about 10 miles east of Mason, where Williamson was working as foreman, and arrested him, to deliver him for trial the next day in Mason. Williamson did not resist. When they had ridden a few miles west, in the area of the Leifeste community, they were met by a hooded mob who relieved the complaisant Deputy Worley of his prisoner. Pleading for his life, Williamson was shot down in cold blood. Again, mob members were never named, but they were generally understood to have included Karl and Peter Bader, Dan Hoerster, and other German settlers. And it was also understood that Worley was part of the plot.

News of the murder of Tim Williamson, a widely known and popular cattleman, spread like wildfire among the Scotch-Irish community. Word soon reached Scott Cooley, ranching about 50 miles west on the San Saba River. Within days, Cooley had come to Mason, where he was not known. He hung around the saloons and livery stables, unobtrusively listening to the town talk. He got his revolver repaired by the local gunsmith. After several weeks, he had heard enough. He went back to the San Saba valley, where he quietly settled up his affairs, and then dropped out of sight.

In mid-July, Scott Cooley reappeared in Mason, inquiring as to the whereabouts of Deputy Sheriff John Worley. Told that Worley was cleaning out a well about a mile west of town, Cooley rode to the well site, where he drew down on the Deputy, curtly informed him of his vengeful mission, shot the man down, scalped him, and disappeared. A few days later, in company with two compatriots, George Gladden and John Baird, Cooley appeared in eastern Mason County, in the Leifeste community, where they murdered Karl Bader. Gladden and Baird had ties to the D.W. Roberts gang of cattle rustlers. The trio of gunmen once again dropped out of sight.

Scott Cooleyís vengeful purpose was now widely recognized, and the Mason County War was now fully joined. Armed bands of hooded night-riders—"hoo-doos"—of both factions now roamed the region, looking for trouble. Shootings were frequent. Twice the town was occupied briefly by a small army of gun-bearing cowboys. In early September a Mason gambler named Turk Chaney was sent by Sheriff Clark to Loyal Valley with a message designed to lure Gladden to Mason. A posse of more than 40 young German minutemen, led by John Clark and Dan Hoerster, ambushed Gladden and John Baird's brother Moses on the road, at Keller's store on the Llano River. Moses Baird was killed. Though severely wounded, George Gladden escaped and survived. While he was recuperating at Loyal Valley, Scott Cooley, John Baird and a new sidekick, John Ringo—of later infamy at Tombstone, Arizona—rode boldly up to the front porch of Turk Chaney's house in Mason town and shot the gambler down in front of his wife and family, then repaired to the Mason Hotel where they casually ordered breakfast. Sheriff John Clark made no attempt to arrest them.

By now Texas Adjutant General William Steele was alarmed. He instructed Major Jones to take a company of the Frontier Battalion to Mason and restore order to the community. Before the Rangers could arrive, however, Scott Cooley, John Baird, and the partly recovered George Gladden rode into Mason, and crept into an alleyway across from the Southern Hotel, from which they ambushed and assassinated Dan Hoerster on the main street in broad daylight. An extended gun fight ensued, between Cooley and his partners and several of Hoerster's German colleagues. It ended when Cooley and Baird, holding their weakened partner in his saddle, rode out of town in a hail of gunfire.

That afternoon, September 21, 1875, Major Jones and 40 Texas Rangers rode into Mason. They had already experienced a near-fatal encounter with Sheriff Clark and his German minutemen the day before at Kelleris store, where the Rangers had been mistaken for a band of cowboys on the warpath, and nearly ambushed. The Rangers set up camp at the old fort, just south of town, and began sending out patrols, restoring order to the area. Major Jones began interviewing townspeople and ranchers, trying to reconstruct the events. Within a few days, things began to settle down, and some of the Rangers were ordered to return to their company in Kerr County. Their places were taken by Rangers from Company D, Scott Cooley's old company, led by Lieutenant Dan Roberts.

For days, Major Jones sent out numerous details, searching for Cooley and his friends, but they could not be found. One young Ranger who stopped for dinner in a cow camp west of Mason found Cooley quite by accident, but was disarmed and sent back to Mason by the wanted man at gunpoint. Before starting him on his way, however, Cooley gave the embarrassed Ranger a package to deliver to "his old bunkie, Maje Reynolds," who opened it in camp, in company with his Ranger friends. The package contained the crusty scalp of Deputy Sheriff John Worley.

Impatient with the lack of success in apprehending Cooley, Major Jones finally insisted that his men either carry out their duty, or resign. Three men stepped forward and mustered out. One of them was Sergeant N.O. Reynolds. Lieutenant Dan Roberts was sent back to Menard, to resume patrolling for Indians.

The Frontier Battalion never did capture Scott Cooley, or any of his compatriots, who were sheltered, fed and hidden by sympathetic friends and allies. It seems probable that the Rangers didn't look too hard.

However, Major Jones did force the resignation of Sheriff John Clark in October, 1875. The Rangers escorted him quietly out of the country, and out of sight. One of the enduring mysteries of the Hoo-Doo War is the fate of ex-Sheriff Clark, who was buried in a family plot at Lone Grove, north of Llano, in January, 1878. Cause and location of his death are unknown. However, he was despised by the Scotch-Irish faction as a traitor, and it is not overly dramatic to suppose that his death may have been from other than natural causes, perhaps related to the Hoo-Doo War.

Finally, in November, 1875, Cooley and John Ringo were captured by Burnet County Sheriff A.J. Strickland near Kingsland, then transferred to jail in Austin. Later both outlaws were moved to the Lampasas jail awaiting trial in District Court. But a friendly mob liberated Cooley and Ringo from the Lampasas jail in early March, 1876.

Cooley was seen briefly in Mason County, then went into hiding, probably near Fredericksburg. In early June he showed up before dawn at the home of Wid Phelps, near what is now Hye post office, deathly ill. He had apparently been given a bottle of arsenic-laced whiskey "for the road" by a vengeful German barmaid at the Nimitz Hotel saloon, who recognized him. Wid Phelps and his wife put Cooley in their wagon, covered him with blankets and drove him to the home of their kinsman, Dan Mattox, at the Miller Creek community, about 20 miles to the east. A local doctor attended him, without success.

Scott Cooley died on or about June 12, 1876, aged 21 years. His friends buried him among their families and neighbors in the Miller Creek Cemetery, which lies just north of U.S. Highway 290, along the field trip route. Interestingly, Miller Creek originates by springflow from the edge of the Edwards Plateau, on the Bamberger Ranch, the focus of this field trip.

For more than four months after Dan Hoerster's murder, Peter Bader had been in hiding at the ranch of Hoerster's in-laws, the Winkels, in western Llano County. Finally in January, 1876, while Scott Cooley and John Ringo were in the Austin jail, George Gladden and John Baird got wind of his whereabouts, laid in wait for him along the road from San Fernando Creek to his hideout, and killed him from ambush. Baird scalped his victim, then recovered—by amputation—the gold ring of his late brother Moses, whom Bader had killed at Keller's store. It was the last official killing of the Hoo-Doo war. Scott Cooleyís sworn vengeance was completed by his friends.

Baird then left the country, and went to New Mexico, where he was killed a few years later in a gunfight. In December, 1876, George Gladden was tried in Llano and convicted of Peter Bader's murder. He served eight years in prison before being pardoned. Gladden relocated to southern Arizona, where he was briefly involved in another range war (the Grass Valley War) but left the country before the struggle climaxed. Later he tended bar in El Paso before finally disappearing from view in about 1890.

Major Jones and the Frontier Battalion finally succeed in bringing law and order to the Texas Hill Country. They cleaned the rustlers out of Llano County in 1876 and Lampasas County in 1877, and then moved west where they repeated the process in Kimble County in 1877-1880. Maje Reynolds had reenlisted a few months after his resignation, and he led the Lampasas and Kimble County campaigns as Lieutenant of Company E. His comrades described him as "Reynolds the intrepid".

Indian raids in the Hill Country had ended by 1878. But the latent hostilities of the Mason County War lingered for generations, rekindled by anti-German sentiment during World Wars I and II. Even though the old difficulties are long past, and the two communities, Scotch-Irish and German, are now essentially integrated, some relict separateness still lingers, and most folks prefer not to talk about the Hoo-Doo War in open company.

Tribalism dies hard.

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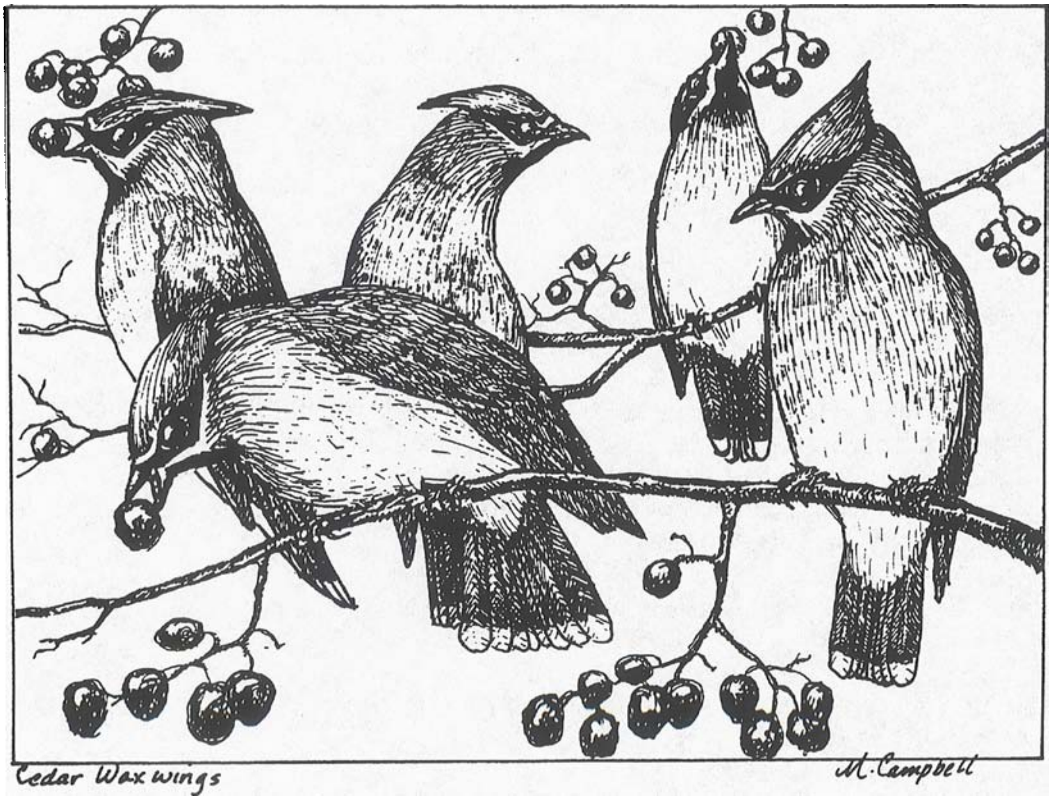


Cedar Wax wings

Road Log—Austin to Bamberger Ranch, Blanco County, Texas

C.M. Woodruff, Jr., Robert W. Baumgardner, Jr., and David H. Riskind

0.0 Depart Sid Richardson Hall parking lot, Manor at Red River; proceed south on Red River to 15th Street.

0.7 At 15th Street, turn right and proceed west to MoPac Expressway (Loop 1).

2.5 Turn left onto southbound access road for Loop 1.

3.0 Merge left onto Loop 1

3.5 Cross Town Lake; note line of hills that compose the Balcones Escarpment on skyline to the west.

5.6 Note apartments built on over-steepened slopes below Barton Creek Mall; pass exit for north-bound Loop 360; continue south on Loop 1.

6.2 At exit for south-bound Loop 360, note roadcut with Edwards Limestone faulted against Georgetown Formation.

6.6 Cross Barton Creek; this part of the creek lies within a City Greenbelt designed to provide protection to the Edwards aquifer and to provide public access to the creek.

8.4 After crossing high overpass, merge onto U.S. 290-West (still under construction).

10.2 Cross Williamson Creek; a rather slimy part of a major recharge reach.

10.4 Cross Mount Bonnell Fault; we cross from Edwards Limestone to Glen Rose Limestone (exposed in cut on the south side of road); we remain on Glen Rose terrain for the remainder of the drive to the ranch.

10.8 Oak Hill "Y"; continue west on U.S. 290.

12.2 On left is Ranch Road (RR) 1826—Camp Ben McCullough Road; proceed straight.

12.9 For approximately the next half-mile, we are straddling the drainage divide separating the Williamson Creek watershed from that of Barton Creek.

13.3 Here we leave the edge of the Williamson Creek basin; Slaughter Creek watershed lies to the left.

13.7 Circle Drive enters 290 on right.

14.0 To the right, note fill material placed along headwater swale. Is this violation of a City ordinance? Is this land controlled by the City?

16.5 Circle Drive intersection on right; we are in greater Cedar Valley, Texas.

17.5 Enter Hays County; here we are crossing from the headwaters of Slaughter Creek into headwaters draining to Bear Creek.

18.2 Nutty Brown Road on left; for the next half-mile or so, we traverse the divide separating the Bear Creek basin from the Barton Creek watershed.

19.3 Roadside Park on left side of road; as we crest this hill, we cross into the Barton Creek watershed.

21.4 Here we cross the 98th Meridian. This is the boundary of the "institutional fault" of Walter Prescott Webb, marking the beginning of the American West (see discussion in first paper by Woodruff, this volume).

21.8 Cross into watershed of Onion Creek.

22.0 Note fill material placed in draw on right.

22.9 From this high point, we are descending into the Onion Creek watershed, where we remain until crossing into the Pedernales basin.

25.6 At traffic light in Dripping Springs we are crossing State Highway 12; from here we traverse low rolling Hill Country.

27.6 Dripping Springs High School on left; a nice modern adaptation of vernacular architecture (stone masonry).

30.8 Note good expression of stairstep hills typical of Glen Rose Limestone; soils on these landforms are discussed by Wilding (this volume).

33.6 Here we cross from the Onion Creek watershed to that of the Pedernales River; we will straddle the divide more or less from "downtown" Henly to the western link of the Henly Loop.

34.1 Henly Loop/downtown Henly on right; intersection with RR 165, the spectacular back road to Blanco is ahead on left. Here we are crossing an alluvial plain that straddles the watershed divide between the Onion Creek and Pedernales basins. The topographic map suggests that part of the Onion Creek watershed has been beheaded by the high-gradient drainage to Pedernales River. The same process has probably taken unknown headwaters of the Barton Creek watershed as well.

35.0 Past the western end of the Henly Loop, we cross into the Pedernales watershed.

35.6 Hays/Blanco County line; also, RR 3232 to Pedernales Falls State Park on right.

39.0 Cross Yaeger Creek.

40.0 Territorial imperative (?) on U.S. 290; note "Dueling Gates"—grandiose structures facing each other on left and right sides of road.

40.6 Cross Middle Creek.

41.5 Pass roadside park on left; overview of Valley of miller Creek on right.

42.2 Miller Creek Cemetery on right; burial place of Scott Cooley, former Texas Ranger and principal involved in Mason County Range War (Rose, this volume).

42.4 Cross McCall Creek.

43.7 Roadside park on right.

44.5 Cross Turkey Creek.

45.2 Intersection U.S. Highway 290 with U.S. 281; turn right and cross Miller Creek.

45.3 Immediately after crossing Miller Creek, turn left onto Blanco County Road 203 (Miller Creek Rd).

47.0 Cross low-water crossing; note exposed Glen Rose Limestone.

47.2 Here we see Miller Creek cut into Glen Rose Limestone surrounded by a wide alluvial valley.

47.5 On left is sign denoting the "largest live oak in Blanco County."

47.9 Fork in road; stay on right-hand fork (paved road).

49.2 Two mail boxes and small sign on left denotes intersection with road to Bamberger Ranch; turn left. Promontory up creek valley on right is Monument Hill, for which this Quadrangle Map is named.

49.5 On left is entrance to M. Gibson Ranch; continue right to Bamberger Ranch.

49.9 Entrance gate to Selah-Bamberger Ranch.

50.0 Low-water crossing.

50.5 Historical marker/"grave"; Stop 1.

This marks the beginning of the tour of the ranch. Owing to the vagaries of weather (hence, accessibility of various sites) and oryx locations on the day of the trip, the route will be somewhat extemporaneous. Therefore, the road log is discontinued here; the return trip to Austin is identical to the route taken out, so the road log will be the reverse of the outgoing log.

This tour of the ranch will include a visit to a soil pit dug across a riser-tread section of a Glen Rose stair-step (see Wilding, this volume); a visit to a bordering fence line of the ranch for a "before-and-after" view of Mr. Bamberger's land-management efforts (for a report on native grasses, see paper by Dunlap, this volume; for bird habitats, see Campbell and Sexton, this volume); a visit to a spring site, which is part of the ranch water-collection program (the ranch uses only spring water; no water wells are employed—see paper by Ashworth, this volume); a view that contrasts the Edwards Plateau uplands from dissected Hill Country (see papers by Woodruff and Nance, this volume); and a view of ranch habitats (see papers by Riskind and Evans, this volume).

One stop has no accompanying paper—this is the exposure of dinosaur tracks in Edwards Limestone. We do, however, have a map of this trackway, courtesy of Jeff Pittman, of the University of Colorado at Denver. This depiction is presented on the following page (Figure 1).

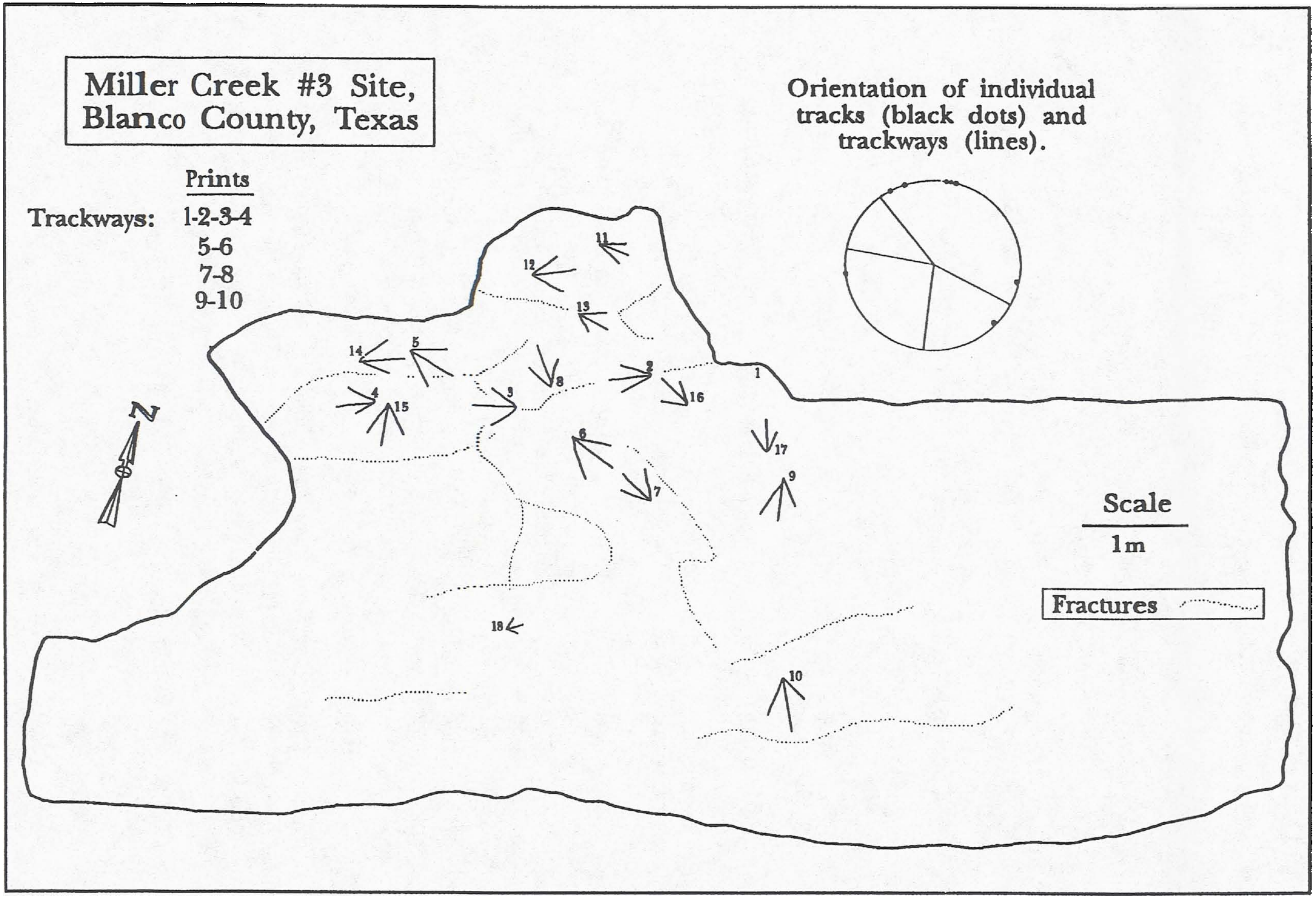


Figure 1. Dinosaur tracks in Edwards Limestone exposed on Bamberger Ranch; map courtesy of Jeffrey Pittman; his home-page address is: jpittman@carbon.cudenver.edu

AFFILIATIONS AND ADDRESSES OF CONTRIBUTORS

John B. Ashworth, Geologist
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711

J. David Bamberger, Land Steward
Selah, Bamberger Ranch
RR 1, Box 102
Johnson City, Texas 78636

Robert W. Baumgardner, Jr., Photographer
12911 Trailwood Road
Austin, Texas 78727

Margaret C. Campbell
c/o Educational Programs
Selah, Bamberger Ranch
RR 1, Box 102
Johnson City, Texas 78636

David W. Dunlap
Texas Department of Transportation
Environmental Affairs Division
125 East 11th Street
Austin, Texas 78701

Glen L. Evans
9011 Fairway Hill
Austin, Texas 78750

H. Seay Nance, Consulting Geologist
25601 River Fern Court
Leander, Texas 78641

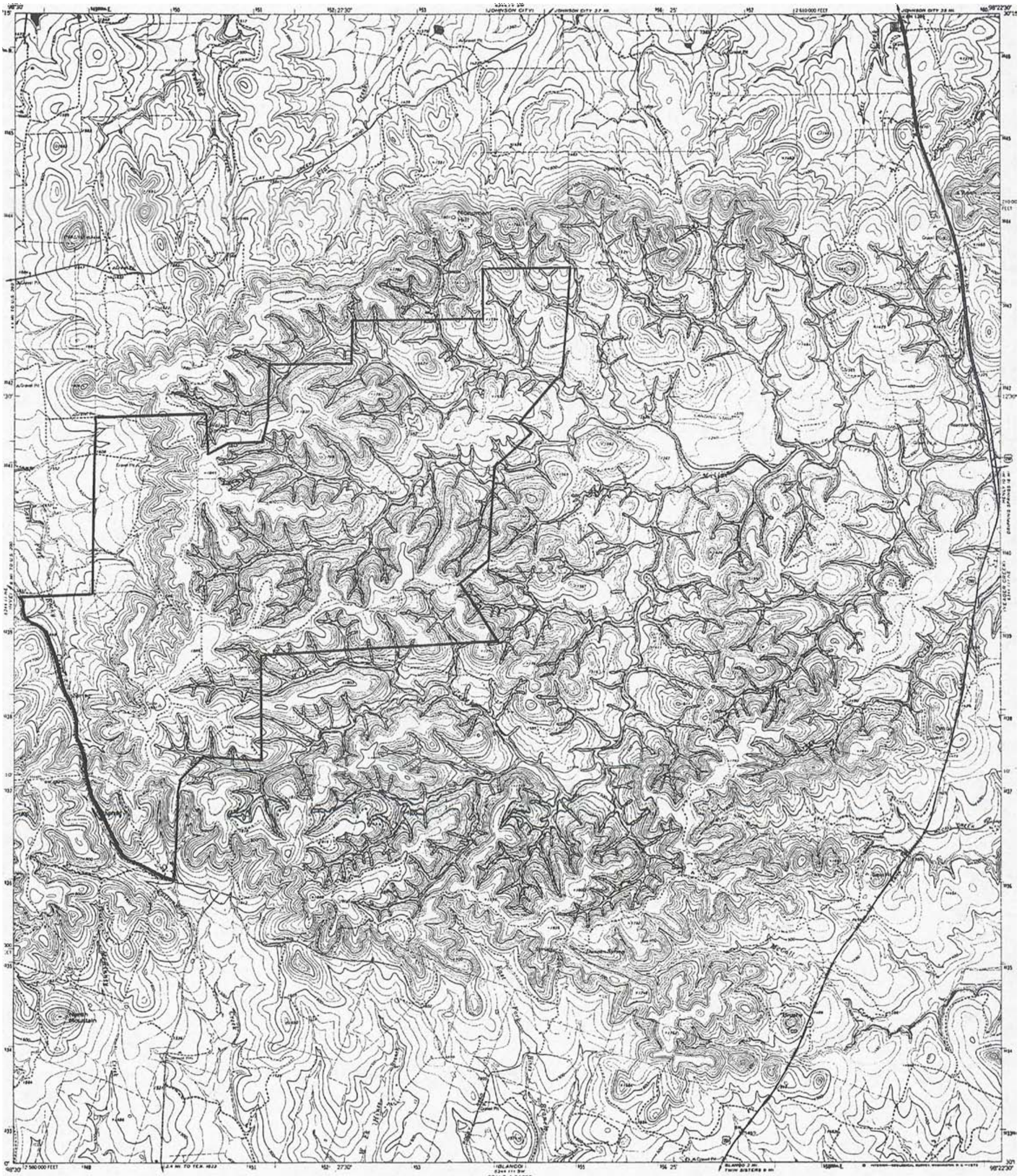
David H. Riskind, Program Director
Natural Resources
Texas Parks & Wildlife Department
4200 Smith School Road
Austin, Texas 78744

Peter R. Rose, Certified Professional Geologist
Telegraph Exploration, Inc.
711 West 14th Street
Austin, Texas 78701

Charles W. Sexton, Wildlife Biologist
U.S. Fish & Wildlife Service
10711 Burnet Road
Austin, Texas 78758

L. P. Wilding, Professor
Department of Soil & Crop Science
Texas A&M University
College Station, Texas 77843

C.M. Woodruff, Jr., Consulting Geologist
711 West 14th Street
Austin, Texas 78701



Monument Hill Quadrangle with Bamberger Ranch highlighted; also water-gathering slopes show the drainage network within Miller Creek watershed. Base map reduced to scale of 1:62,500; contour interval = 20 ft.